US009462662B1

(12) **United States Patent**
Reed

(10) **Patent No.: US 9,462,662 B1**
(45) **Date of Patent: Oct. 4, 2016**

(54) **LOW POWER PHOTOCONTROL FOR LUMINAIRE**

(71) Applicant: **Express Imaging Systems, LLC**, Renton, WA (US)

(72) Inventor: **William G. Reed**, Seattle, WA (US)

(73) Assignee: **EXPRESS IMAGING SYSTEMS, LLC**, Renton, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/994,569**

(22) Filed: **Jan. 13, 2016**

Related U.S. Application Data

(60) Provisional application No. 62/137,666, filed on Mar. 24, 2015.

(51) **Int. Cl.**
H05B 37/02 (2006.01)

(52) **U.S. Cl.**
CPC ***H05B 37/0218*** (2013.01)

(58) **Field of Classification Search**
CPC H05B 37/0218; H05B 37/03; H05B 37/0281; H05B 33/0815; Y02B 20/46; Y02B 20/42; Y02B 20/72; Y02B 20/346; Y02B 20/40
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,240,050	A	4/1941	Nuebling
2,745,055	A	5/1956	Woerdemann
3,374,396	A	3/1968	Bell et al.
4,153,927	A	5/1979	Owens
4,237,377	A	12/1980	Sansum
4,663,521	A	5/1987	Maile
5,086,379	A	2/1992	Denison et al.
5,160,202	A	11/1992	Légaré
5,161,107	A	11/1992	Mayeaux et al.
5,230,556	A	7/1993	Canty et al.
5,276,385	A	1/1994	Itoh et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE	40 01 980 A1	8/1990
EP	1 734 795 A1	12/2006

(Continued)

OTHER PUBLICATIONS

"Lcd Backlight I/O Ports and Power Protection Circuit Design," dated May 2, 2011, retrieved Jun. 10, 2011, retrieved from http://www.chipoy.info/gadgets/lcd-backlight-i-o-ports-and-power-pr . . . , 4 pages.

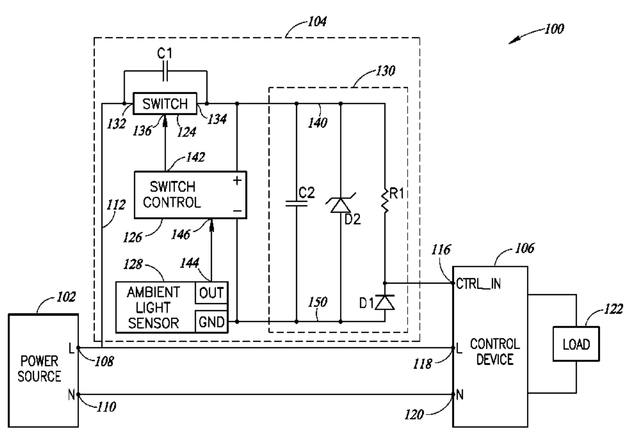
(Continued)

Primary Examiner — Jany Richardson
(74) *Attorney, Agent, or Firm* — Seed IP Law Group PLLC

(57) **ABSTRACT**

Photocontrol apparatus that controls a luminaire or other load such that the luminaire is switched on during nighttime hours and off during the daytime. The photocontrol generates a micro-amp power supply using the voltage generated across a high value resistor in series with an alternating current (AC) power line. The photocontrol consumes only microwatts of power in either the ON or the OFF state, unlike traditional relay- or triac-based photocontrols. The photocontrol does not require a voltage generating photo sensor to generate power for the photocontrol. A solar cell, semiconductor photo diode or photo diode string, cadmium sulfide cell, semiconductor ambient light sensor, etc., may be used as the sensor element.

28 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

5,343,121 A	8/1994	Terman et al.	
5,349,505 A	9/1994	Poppenheimer	
5,450,302 A	9/1995	Maase et al.	
5,561,351 A	10/1996	Vrionis et al.	
5,589,741 A	12/1996	Terman et al.	
5,808,294 A	9/1998	Neumann	
5,869,960 A	2/1999	Brand	
5,892,331 A	4/1999	Hollaway	
5,892,335 A	4/1999	Archer	
5,936,362 A	8/1999	Alt et al.	
6,111,739 A	8/2000	Wu et al.	
6,149,283 A	11/2000	Conway et al.	
6,154,015 A	11/2000	Ichiba	
6,160,353 A	12/2000	Mancuso	
6,377,191 B1	4/2002	Takubo	
6,452,339 B1 *	9/2002	Morrissey	H05B 37/03 315/119
6,612,720 B1	9/2003	Beadle	
6,674,060 B2	1/2004	Antila	
6,681,195 B1	1/2004	Poland et al.	
6,746,274 B1	6/2004	Verfuerth	
6,753,842 B1	6/2004	Williams et al.	
6,828,911 B2	12/2004	Jones et al.	
6,841,947 B2	1/2005	Berg-johansen	
6,902,292 B2	6/2005	Lai	
6,985,827 B2	1/2006	Williams et al.	
7,019,276 B2	3/2006	Cloutier et al.	
7,066,622 B2	6/2006	Alessio	
7,081,722 B1	7/2006	Huynh et al.	
7,122,976 B1	10/2006	Null et al.	
7,188,967 B2	3/2007	Dalton et al.	
7,190,121 B2	3/2007	Rose et al.	
7,196,477 B2	3/2007	Richmond	
7,239,087 B2	7/2007	Ball	
7,252,385 B2	8/2007	Engle et al.	
7,258,464 B2	8/2007	Morris et al.	
7,270,441 B2	9/2007	Fiene	
7,281,820 B2	10/2007	Bayat et al.	
7,294,973 B2	11/2007	Takahama et al.	
7,314,291 B2	1/2008	Tain et al.	
7,317,403 B2	1/2008	Grootes et al.	
7,322,714 B2	1/2008	Barnett et al.	
7,330,568 B2	2/2008	Nagaoka et al.	
7,339,323 B2	3/2008	Bucur	
7,339,471 B1	3/2008	Chan et al.	
7,405,524 B2	7/2008	Null et al.	
7,438,440 B2	10/2008	Dorogi	
7,440,280 B2	10/2008	Shuy	
7,468,723 B1	12/2008	Collins	
7,524,089 B2	4/2009	Park	
7,538,499 B2	5/2009	Ashdown	
7,547,113 B2	6/2009	Lee	
7,559,674 B2	7/2009	He et al.	
7,564,198 B2	7/2009	Yamamoto et al.	
7,569,802 B1	8/2009	Mullins	
7,578,596 B2	8/2009	Martin	
7,578,597 B2	8/2009	Hoover et al.	
7,627,372 B2	12/2009	Vaisnys et al.	
7,631,324 B2	12/2009	Buonasera et al.	
7,633,463 B2	12/2009	Negru	
7,638,743 B2	12/2009	Bartol et al.	
7,677,753 B1	3/2010	Wills	
7,688,002 B2	3/2010	Ashdown et al.	
7,688,222 B2	3/2010	Peddie et al.	
7,702,135 B2	4/2010	Hill et al.	
7,703,951 B2	4/2010	Piepgras et al.	
7,746,003 B2	6/2010	Verfuerth et al.	
D621,410 S	8/2010	Verfuerth et al.	
D621,411 S	8/2010	Verfuerth et al.	
7,798,669 B2	9/2010	Trojanowski et al.	
7,804,200 B2	9/2010	Flaherty	
7,828,463 B1	11/2010	Willis	
7,834,922 B2	11/2010	Kurane	
7,932,535 B2	4/2011	Mahalingam et al.	
7,940,191 B2	5/2011	Hierzer	
7,952,609 B2	5/2011	Simerly et al.	
7,960,919 B2	6/2011	Furukawa	
7,983,817 B2	7/2011	Breed	
7,985,005 B2	7/2011	Alexander et al.	
8,100,552 B2	1/2012	Spero	
8,118,456 B2	2/2012	Reed et al.	
8,143,769 B2	3/2012	Li	
8,174,212 B2	5/2012	Tziony et al.	
8,207,830 B2	6/2012	Rutjes et al.	
8,290,710 B2	10/2012	Cleland et al.	
8,334,640 B2	12/2012	Reed et al.	
8,344,665 B2	1/2013	Verfuerth et al.	
8,376,583 B2	2/2013	Wang et al.	
8,378,563 B2	2/2013	Reed et al.	
8,395,329 B2	3/2013	Jutras et al.	
8,445,826 B2	5/2013	Verfuerth	
8,450,670 B2	5/2013	Verfuerth et al.	
8,476,565 B2	7/2013	Verfuerth	
8,508,137 B2	8/2013	Reed	
8,541,950 B2	9/2013	Reed	
8,586,902 B2	11/2013	Verfuerth	
8,604,701 B2	12/2013	Verfuerth et al.	
8,610,358 B2	12/2013	Reed	
8,629,621 B2	1/2014	Reed	
8,749,635 B2	6/2014	Högasten et al.	
8,764,237 B2	7/2014	Wang et al.	
8,779,340 B2	7/2014	Verfuerth et al.	
8,779,686 B2	7/2014	Jin	
8,810,138 B2	8/2014	Reed	
8,866,392 B2	10/2014	Chen	
8,866,582 B2	10/2014	Verfuerth et al.	
8,872,430 B2	10/2014	Yang	
8,872,964 B2	10/2014	Reed et al.	
8,878,440 B2	11/2014	Reed	
8,884,203 B2	11/2014	Verfuerth et al.	
8,896,215 B2	11/2014	Reed et al.	
8,901,825 B2	12/2014	Reed	
8,921,751 B2	12/2014	Verfuerth	
8,922,124 B2	12/2014	Reed et al.	
8,926,138 B2	1/2015	Reed et al.	
8,926,139 B2	1/2015	Reed et al.	
8,987,992 B2	3/2015	Reed	
9,084,310 B2	7/2015	Bedell et al.	
9,210,751 B2	12/2015	Reed	
9,210,759 B2	12/2015	Reed	
2002/0084767 A1	7/2002	Arai	
2003/0016143 A1	1/2003	Ghazarian	
2003/0184672 A1	10/2003	Wu et al.	
2004/0192227 A1	9/2004	Beach et al.	
2005/0117344 A1	6/2005	Bucher et al.	
2005/0174762 A1	8/2005	Fogerlie	
2005/0231133 A1	10/2005	Lys	
2006/0014118 A1	1/2006	Utama	
2006/0066264 A1	3/2006	Ishigaki et al.	
2006/0098440 A1	5/2006	Allen	
2006/0146652 A1	7/2006	Huizi et al.	
2006/0208667 A1	9/2006	Lys et al.	
2007/0032990 A1	2/2007	Williams et al.	
2007/0102033 A1	5/2007	Petrocy	
2007/0153524 A1 *	7/2007	Lee	H05B 37/0218 362/276
2007/0164689 A1	7/2007	Suzuki	
2007/0224461 A1	9/2007	Oh	
2007/0225933 A1	9/2007	Shimomura	
2008/0018261 A1	1/2008	Kastner	
2008/0043106 A1	2/2008	Hassapis et al.	
2008/0062687 A1	3/2008	Behar et al.	
2008/0130304 A1	6/2008	Rash et al.	
2008/0215279 A1	9/2008	Salsbury et al.	
2008/0224623 A1	9/2008	Yu	
2008/0232116 A1	9/2008	Kim	
2008/0248837 A1	10/2008	Kunkel	
2008/0266839 A1	10/2008	Claypool et al.	
2009/0046151 A1	2/2009	Nagaoka et al.	
2009/0058320 A1	3/2009	Chou et al.	
2009/0129067 A1	5/2009	Fan et al.	
2009/0153062 A1	6/2009	Guo et al.	
2009/0160358 A1	6/2009	Leiderman	
2009/0161356 A1	6/2009	Negley et al.	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2009/0167203 A1	7/2009	Dahlman et al.	
2009/0195179 A1	8/2009	Joseph et al.	
2009/0230883 A1	9/2009	Haug	
2009/0235208 A1	9/2009	Nakayama et al.	
2009/0261735 A1	10/2009	Sibalich et al.	
2009/0268023 A1	10/2009	Hsieh	
2009/0273290 A1	11/2009	Ziegenfuss	
2009/0278479 A1	11/2009	Platner et al.	
2010/0001652 A1	1/2010	Damsleth	
2010/0052557 A1	3/2010	Van Der Veen et al.	
2010/0096460 A1	4/2010	Carlson et al.	
2010/0123403 A1	5/2010	Reed	
2010/0164406 A1	7/2010	Kost et al.	
2010/0171442 A1	7/2010	Draper et al.	
2010/0244708 A1	9/2010	Cheung et al.	
2010/0259193 A1	10/2010	Umezawa et al.	
2010/0270945 A1	10/2010	Chang et al.	
2010/0271802 A1	10/2010	Recker et al.	
2010/0309310 A1	12/2010	Albright	
2010/0328946 A1	12/2010	Borkar et al.	
2011/0001626 A1	1/2011	Yip et al.	
2011/0006703 A1	1/2011	Wu et al.	
2011/0026264 A1	2/2011	Reed et al.	
2011/0204845 A1	8/2011	Paparo et al.	
2011/0215731 A1	9/2011	Jeong et al.	
2011/0221346 A1	9/2011	Lee et al.	
2011/0248812 A1	10/2011	Hu et al.	
2011/0251751 A1	10/2011	Knight	
2011/0260624 A1*	10/2011	Bigge	H05B 37/02 315/119
2011/0310605 A1	12/2011	Renn et al.	
2012/0001566 A1	1/2012	Josefowicz et al.	
2012/0019971 A1	1/2012	Flaherty et al.	
2012/0038490 A1	2/2012	Verfuerth	
2012/0119669 A1	5/2012	Melanson et al.	
2012/0119682 A1	5/2012	Warton	
2012/0143383 A1	6/2012	Cooperrider et al.	
2012/0153854 A1	6/2012	Setomoto et al.	
2012/0169053 A1	7/2012	Tchoryk, Jr. et al.	
2012/0181935 A1	7/2012	Velazquez	
2012/0209755 A1	8/2012	Verfuerth et al.	
2012/0221154 A1	8/2012	Runge	
2012/0224363 A1	9/2012	Van De Ven	
2012/0230584 A1	9/2012	Kubo et al.	
2012/0242254 A1	9/2012	Kim et al.	
2013/0033183 A1	2/2013	Verfuerth et al.	
2013/0126715 A1	5/2013	Flaherty	
2013/0131882 A1	5/2013	Verfuerth et al.	
2013/0141000 A1	6/2013	Wei et al.	
2013/0154488 A1	6/2013	Sadwick et al.	
2013/0163243 A1	6/2013	Reed	
2013/0193857 A1	8/2013	Tlachac et al.	
2013/0229518 A1	9/2013	Reed et al.	
2013/0235202 A1	9/2013	Nagaoka et al.	
2013/0249429 A1	9/2013	Woytowitz et al.	
2013/0249479 A1	9/2013	Partovi	
2013/0293112 A1	11/2013	Reed et al.	
2013/0340353 A1	12/2013	Whiting et al.	
2014/0001961 A1	1/2014	Anderson et al.	
2014/0028198 A1	1/2014	Reed et al.	
2014/0055990 A1	2/2014	Reed	
2014/0070964 A1	3/2014	Rupprath et al.	
2014/0078308 A1	3/2014	Verfuerth	
2014/0097759 A1	4/2014	Verfuerth et al.	
2014/0159585 A1	6/2014	Reed	
2014/0203714 A1	7/2014	Zhang et al.	
2014/0225521 A1*	8/2014	Reed	H05B 37/02 315/201
2014/0244044 A1	8/2014	Davis et al.	
2014/0265894 A1	9/2014	Weaver	
2014/0265897 A1	9/2014	Taipale et al.	
2014/0313719 A1	10/2014	Wang et al.	
2015/0015716 A1	1/2015	Reed et al.	
2015/0028693 A1*	1/2015	Reed	H01H 9/54 307/117
2015/0077019 A1	3/2015	Reed et al.	
2015/0084520 A1	3/2015	Reed	
2015/0137693 A1	5/2015	Reed	
2015/0208479 A1	7/2015	Radermacher et al.	
2015/0280782 A1	10/2015	Arbinger et al.	
2015/0312983 A1	10/2015	Hu et al.	
2016/0021713 A1	1/2016	Reed	

FOREIGN PATENT DOCUMENTS

EP	2 559 937 A1	2/2013
EP	1 459 600 B1	2/2014
EP	2 781 138 A1	9/2014
FR	2 883 306 A1	9/2006
JP	6-335241 A	12/1994
JP	2001-333420 A	11/2001
JP	2004-279668 A	10/2004
JP	2004-320024 A	11/2004
JP	2004-349065 A	12/2004
JP	2005-93171 A	4/2005
JP	2005-198238 A	7/2005
JP	2005-310997 A	11/2005
JP	2006-179672 A	7/2006
JP	2006-244711 A	9/2006
JP	2008-59811 A	3/2008
JP	2008-509538 A	3/2008
JP	2008-130523 A	6/2008
JP	2008-159483 A	7/2008
JP	2008-177144 A	7/2008
JP	2008-529177 A	7/2008
JP	2008-535279 A	8/2008
JP	2010-504628 A	2/2010
KR	10-2005-0078403 A	8/2005
KR	10-2006-0071869 A	6/2006
KR	10-2006-0086254 A	7/2006
KR	10-2009-0042400 A	4/2009
KR	10-0935736 B1	1/2010
KR	20-2010-0007230 U	7/2010
KR	10-1001276 B1	12/2010
KR	10-1044224 B1	6/2011
KR	10-1150876 B1	5/2012
KR	10-1592013 B1	2/2016
WO	02/076068 A1	9/2002
WO	03/056882 A1	7/2003
WO	2005/003625 A1	1/2005
WO	2006/057866 A2	6/2006
WO	2007/023454 A1	3/2007
WO	2007/036873 A2	4/2007
WO	2008/030450 A2	3/2008
WO	2008/034242 A1	3/2008
WO	2009/040703 A2	4/2009
WO	2011/063302 A2	5/2011
WO	2012/142115 A2	10/2012
WO	2013/074900 A1	5/2013
WO	2014/018773 A1	1/2014
WO	2014/039683 A1	3/2014
WO	2011/129309 A1	5/2014
WO	2014/078854 A1	5/2014
WO	2012/006710 A1	3/2016

OTHER PUBLICATIONS

EE Herald, "Devices to protect High brightness LED from ESD," dated Mar. 16, 2009, retrieved Jun. 10, 2011, retrieved from http://www.eeherald.com/section/new-products/np100779.html, 1 page.

Extended European Search Report, dated Aug. 13, 2014, for corresponding European Application No. 09826926.9, 8 pages.

Extended European Search Report, dated Oct. 15, 2015, for corresponding European Application No. 12825132.9-1802, 5 pages.

Extended European Search Report, dated Sep. 28, 2015, for corresponding European Application No. 12850159.0-1802, 6 pages.

Extended European Search Report dated Oct. 21, 2015, for corresponding EP Application No. 13835001.2-1802, 7 pages.

Extended European Search Report dated Jan. 4, 2016, for corresponding EP Application No. 13823055,2-1802, 7 pages.

(56) **References Cited**

OTHER PUBLICATIONS

Fairchild Semiconductor, "LED Application Design Guide Using Half-Bridge LLC Resonant Converter for 100W Street Lighting," AN-9729, Fairchild Semiconductor Corporation, Rev. 1.0.0, Mar. 22, 2011, 17 pages.
Huang, "Designing an LLC Resonant Half-Bridge Power Converter," 2010 Texas Instruments Power Supply Design Seminar, SEM1900, Topic 3, TI Literature No. SLUP263, Copyright 2010, 2011, Texas Instruments Incorporated, 28 pages.
International Search Report, mailed Jul. 9, 2009 for PCT/US2009/043171, 5 pages.
International Search Report, mailed Jun. 21, 2010 for PCT/US2009/064625, 3 pages.
International Search Report, mailed Dec. 13, 2010 for PCT/US2010/035649, 3 pages.
International Search Report, mailed Dec. 15, 2010 for PCT/US2010/035658, 3 pages.
International Search Report, mailed Dec. 28, 2010 for PCT/US2010/035651, 3 pages.
International Search Report, mailed Oct. 8, 2012 for PCT/US2012/033059, 3 pages.
International Search Report, mailed Jan. 14, 2013, for PCT/US2012/052009, 3 pages.
International Search Report, mailed Feb. 27, 2013, for PCT/US2012/065476, 3 pages.
International Search Report, mailed Nov. 19, 2013 for PCT/US2013/052092, 4 pages.
International Search Report, mailed Dec. 30, 2013 for PCT/US2013/058266, 3 pages.
International Search Report mailed Nov. 11, 2014, for International Application No. PCT/US2014/047867, 3 pages.
International Search Report and Written Opinion, mailed May 7, 2015, for International Application No. PCT/US2015/013512, 15 pages.
Japanese Office Action, dated Jan. 6, 2015, for corresponding Japanese Application No. 2011-536564, 6 pages.
Kadirvel et al., "Self-Powered, Ambient Light Sensor Using bq25504," Texas Instruments, Application Report, SLUA629-Jan. 2012, 6 pages.
Korean Office Action with English Translation, dated Nov. 18, 2015, for corresponding Kr Application No. 10-2011-7014088, 14 pages.
Littelfuse, "Application Note: Protecting LEDs in Product Designs," 2009, 2 pages.
Panasonic Electronic Components, "LED Lighting Solutions," 2009, 6 pages.
Poplawski, "Exploring Flicker & LEDs," 2010 DOE SSL Market Introduction Workshop, U.S. Department of Energy, Jul. 22, 2010, 16 pages.
Reed et al., "Adjustable Output Solid-State Lamp With Security Features," Office Action mailed Feb. 27, 2014, for U.S. Appl. No. 13/679,687, 11 pages.
Reed et al., "Adjustable Output Solid-State Lamp With Security Features," Amendment filed Jun. 24, 2014, for U.S. Appl. No. 13/679,687, 11 pages.
Reed et al., "Adjustable Output Solid-State Lamp With Security Features," Notice of Allowance mailed Aug. 29, 2014, for U.S. Appl. No. 13/679,687, 9 pages.
Reed et al., "Apparatus and Method for Schedule Based Operation of a Luminaire," Office Action mailed Mar. 26, 2014, for U.S. Appl. No. 13/604,327, 10 pages.
Reed et al., "Apparatus and Method for Schedule Based Operation of a Luminaire," Amendment filed Jun. 24, 2014, for U.S. Appl. No. 13/604,327, 14 pages.
Reed et al., "Apparatus and Method for Schedule Based Operation of a Luminaire," Notice of Allowance mailed Jul. 7, 2014, for U.S. Appl. No. 13/604,327, 8 pages.
Reed et al., "Apparatus and Method for Schedule Based Operations of a Luminaire," Office Action mailed Mar. 2, 2015, for U.S. Appl. No. 14/552,274, 7 pages.
Reed et al., "Apparatus and Method for Schedule Based Operation of a Luminaire" Amendment filed Jun. 1, 2015, for U.S. Appl. No. 14/552,274, 14 pages.
Reed et al., "Apparatus and Method for Schedule Based Operation of a Luminaire" Notice of Allowance mailed Jun. 19, 2015, for U.S. Appl. No. 14/552,274, 9 pages.
Reed et al., "Apparatus and Method of Operating a Luminaire," Office Action mailed Dec. 22, 2014, for U.S. Appl. No. 13/558,191, 17 pages.
Reed et al., "Apparatus and Method of Operating a Luminaire," Amendment filed Mar. 19, 2015, for U.S. Appl. No. 13/558,191, 20 pages.
Reed et al., "Apparatus and Method of Operating a Luminaire," Notice of Allowance mailed Apr. 27, 2015, for U.S. Appl. No. 13/558,191, 8 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Office Action mailed Dec. 21, 2012, for U.S. Appl. No. 12/784,080, 26 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Amendment filed Apr. 22, 2013, for U.S. Appl. No. 12/784,080, 17 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Office Action mailed Jul. 22, 2013, for U.S. Appl. No. 12/784,080, 29 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Amendment filed Sep. 27, 2013, for U.S. Appl. No. 12/784,080, 20 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Office Action mailed Jan. 30, 2014, for U.S. Appl. No. 12/784,080, 26 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Amendment filed Apr. 28, 2014, for U.S. Appl. No. 12/784,080, 20 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Notice of Allowance mailed Jun. 20, 2014, for U.S. Appl. No. 12/784,080, 7 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Office Action mailed Sep. 17, 2015, for U.S. Appl. No. 14/500,512, 17 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Amendment filed Dec. 10, 2015, for U.S. Appl. No. 14/500,512, 18 pages.
Reed et al., "Long-Range Motion Detection for Illumination Control," Office Action mailed Mar. 4, 2016, for U.S. Appl. No. 14/500,512, 18 pages.
Reed et al., "Low-Profile Pathway Illumination System," Office Action, dated May 5, 2011, for U.S. Appl. No. 12/437,472, 24 pages.
Reed et al., "Low-Profile Pathway Illumination System," Amendment filed Jul. 29, 2011, for U.S. Appl. No. 12/437,472, 19 pages.
Reed et al., "Low-Profile Pathway Illumination System," Notice of Allowance, dated Oct. 14, 2011, for U.S. Appl. No. 12/437,472, 9 pages.
Reed et al., "Remotely Adjustable Solid-State Lamp," Amendment filed Apr. 1, 2015, for U.S. Appl. No. 13/875,130, 14 pages.
Reed et al., "Remotely Adjustable Solid-State Lamp," Office Action mailed Apr. 21, 2015, for U.S. Appl. No. 13/875,130, 10 pages.
Reed et al., "Remotely Adjustable Solid-State Lamp," Amendment filed Jul. 20, 2015, for U.S. Appl. No. 13/875,130, 15 pages.
Reed et al., "Remotely Adjustable Solid-State Lamp," Corrected Notice of Allowance, mailed Aug. 12, 2015, and Notice of Allowance, mailed Jul. 31, 2015 for U.S. Appl. No. 13/875,130, 11 pages.
Reed et al., "Systems and Methods That Employ Object Recognition," Office Action mailed Aug. 25, 2014, for U.S. Appl. No. 13/411,321, 35 pages.
Reed et al., "Systems and Methods That Employ Object Recognition," Amendment filed Nov. 21, 2014, for U.S. Appl. No. 13/411,321, 20 pages.
Reed et al., "Systems and Methods That Employ Object Recognition," Office Action mailed Feb. 9, 2015, for U.S. Appl. No. 13/411,321, 40 pages.

(56) **References Cited**

OTHER PUBLICATIONS

Reed et al., "Systems and Methods That Employ Object Recognition," Amendment filed May 6, 2015, for U.S. Appl. No. 13/411,321, 20 pages.
Reed et al., "Systems and Methods That Employ Object Recognition," Amendment filed Jul. 7, 2015, for U.S. Appl. No. 13/411,321, 21 pages.
Reed et al., "Systems and Methods That Employ Object Recognition," Office Action mailed Dec. 7, 2015, for U.S. Appl. No. 13/411,321, 47 pages.
Reed et al., "Systems and Methods That Employ Object Recognition," Amendment filed Mar. 7, 2016, for U.S. Appl. No. 13/411,321, 16 pages.
Reed, "Adjustable Output Solid-State Lighting Device," Office Acton mailed Jan. 2, 2015, for U.S. Appl. No. 13/707,123, 24 pages.
Reed, "Adjustable Output Solid-State Lighting Device," Amendment filed Apr. 2, 2015, for U.S. Appl. No. 13/707,123, 14 pages.
Reed, "Adjustable Output Solid-State Lighting Device," Office Action mailed Oct. 5, 2015, for U.S. Appl. No. 13/707,123, 24 pages.
Reed, "Adjustable Output Solid-State Lighting Device," Amendment filed Jan. 8, 2016, for U.S. Appl. No. 13/707,123, 11 pages.
Reed, "Adjustable Output Solid-State Lighting Device," Notice of Allowance mailed Feb. 25, 2016, for U.S. Appl. No. 13/707,123, 9 pages.
Reed, "Ambient Light Control in Solid State Lamps and Luminaires," U.S. Appl. No. 14/609,168, filed Jan. 29, 2015, 77 pages.
Reed, "Ambient Light Control in Solid State Lamps and Luminaires," Amendment filed Jan. 29, 2015, for U.S. Appl. No. 14/609,168, 12 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Office Action mailed Dec. 5, 2012, for U.S. Appl. No. 12/784,091, 18 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Amendment filed Apr. 4, 2013, for U.S. Appl. No. 12/784,091, 15 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Office Action mailed Apr. 24, 2013, for U.S. Appl. No. 12/784,091, 12 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Amendment filed May 14, 2013, for U.S. Appl. No. 12/784,091, 9 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Notice of Allowance mailed May 23, 2013, for U.S. Appl. No. 12/784,091, 6 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Office Action mailed Dec. 5, 2012, for U.S. Appl. No. 12/784,093, 13 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Amendment filed Apr. 2, 2013, for U.S. Appl. No. 12/784,093, 13 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Notice of Allowance mailed Apr. 12, 2013, for U.S. Appl. No. 12/784,093, 9 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Office Action mailed Nov. 27, 2013, for U.S. Appl. No. 13/943,537, 8 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Notice of Allowance mailed Apr. 11, 2014, for U.S. Appl. No. 13/943,537, 9 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Office Action mailed Aug. 28, 2014, for U.S. Appl. No. 14/329,508, 8 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Amendment filed Sep. 30, 2014, for U.S. Appl. No. 14/329,508, 18 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination," Notice of Allowance mailed Nov. 5, 2014, for U.S. Appl. No. 14/329,508, 10 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination Using Received Signals," Office Action mailed Oct. 1, 2013, for U.S. Appl. No. 13/085,301, 11 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination Using Received Signals," Office Action mailed Jan. 2, 2014, for U.S. Appl. No. 13/085,301, 26 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination Using Received Signals," Office Action mailed Apr. 23, 2014, for U.S. Appl. No. 13/085,301, 12 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination Using Received Signals," Amendment filed Jul. 23, 2014, for U.S. Appl. No. 13/085,301, 12 pages.
Reed, "Apparatus and Method of Energy Efficient Illumination Using Received Signals," Notice of Allowance mailed Jul. 30, 2014, for U.S. Appl. No. 13/085,301, 5 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Office Action mailed Feb. 28, 2013, for U.S. Appl. No. 12/619,535, 17 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Amendment filed May 24, 2013, for U.S. Appl. No. 12/619,535, 21 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Office Action mailed Jul. 30, 2013, for U.S. Appl. No. 12/619,535, 15 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Amendment filed Oct. 30, 2013, for U.S. Appl. No. 12/619,535, 5 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Office Action mailed Mar. 26, 2014, for U.S. Appl. No. 12/619,535, 16 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Amendment filed May 27, 2014, for U.S. Appl. No. 12/619,535, 22 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Office Action mailed Aug. 14, 2014, for U.S. Appl. No. 12/619,535, 16 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Amendment filed Dec. 15, 2014, for U.S. Appl. No. 12/619,535, 21 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Notice of Allowance mailed Apr. 23, 2015, for U.S. Appl. No. 12/619,535, 8 pages.
Reed et al., "Electrostatic Discharge Protection for Luminaire," Office Action mailed Mar. 15, 2013 for U.S. Appl. No. 13/212,074, 11 pages.
Reed, "Electrostatic Discharge Protection for Luminaire," Amendment filed Jun. 17, 2013, for U.S. Appl. No. 13/212,074, 11 pages.
Reed, "Electrostatic Discharge Protection for Luminaire," Notice of Allowance mailed Sep. 12, 2013, for U.S. Appl. No. 13/212,074, 6 pages.
Reed, "High Efficiency Power Controller for Luminaire," Office Action mailed Sep. 10, 2015, for U.S. Appl. No. 14/546,354, 15 pages.
Reed, "High Efficiency Power Controller for Luminaire," Amendment filed Feb. 9, 2016, for U.S. Appl. No. 14/546,354, 11 pages.
Reed, "Low Power Photocontrol for Luminaire," U.S. Appl. No. 14/844,944, filed Sep. 3, 2015, 45 pages.
Reed et al., "Luminaire With Adjustable Illumination Pattern," U.S. Appl. No. 14/939,856, filed Nov. 12, 2015, 69 pages.
Reed, "Luminaire With Atmospheric Electrical Activity Detection and Visual Alert Capabilities," Notice of Allowance mailed Jul. 1, 2014, for U.S. Appl. No. 13/786,114, 9 pages.
Reed, "Luminaire With Switch-Mode Converter Power Monitoring," Notice of Allowance mailed Nov. 18, 2015, for U.S. Appl. No. 14/074,166, 9 pages.
Reed, "Resonant Network for Reduction of Flicker Perception in Solid State Lighting Systems," Notice of Allowance mailed Sep. 30, 2013, for U.S. Appl. No. 13/592,590, 9 pages.
Reed, "Solid State Lighting, Drive Circuit and Method of Driving Same," Notice of Allowance Mailed Aug. 4, 2015, for U.S. Appl. No. 13/875,000, 10 pages.

(56) **References Cited**

OTHER PUBLICATIONS

Reed, "Systems, Methods, and Apparatuses for Using a High Current Switching Device As a Logic Level Sensor," Notice of Allowance for U.S. Appl. No. 14/179,737, mailed Nov. 6, 2015, 9 pages.
Renesas Electronics, "Zener Diodes for Surge Absorption—Applications of high-intensity LED," Apr. 2010, 1 page.
Tyco Electronics, "Circuit Protection," retrieved Jun. 10, 2011, retrieved from http://www.tycoelectronics.com/en/products/circuit-protection.html, 2 pages.
Written Opinion, mailed Jul. 9, 2009 for PCT/US2009/043171, 8 pages.
Written Opinion, mailed Jun. 21, 2010 for PCT/US2009/064625, 5 pages.
Written Opinion, mailed Dec. 13, 2010 for PCT/US2010/035649, 4 pages.
Written Opinion, mailed Dec. 15, 2010 for PCT/US2010/035658, 3 pages.
Written Opinion, mailed Dec. 28, 2010 for PCT/US2010/035651, 3 pages.
Written Opinion, mailed Oct. 8, 2012 for PCT/US2012/033059, 3 pages.
Written Opinion, mailed Jan. 14, 2013, for PCT/US2012/052009, 5 pages.
Written Opinion, mailed Feb. 27, 2013, for PCT/US2012/065476, 8 pages.
Written Opinion, mailed Nov. 19, 2013 for PCT/US2013/052092, 7 pages.
Written Opinion, mailed Dec. 30, 2013 for PCT/US2013/058266, 8 pages.
Written Opinion mailed Nov. 11, 2014, for International Application No. PCT/US2014/047867, 5 pages.
Extended European Search Report, dated Apr. 11, 2016, for corresponding European Application No. 16152644.7, 8 pages.
Extended European Search Report, dated May 3, 2016, for corresponding European Application No. 12771286.7, 9 pages.
Reed, "Electronic Control to Regulate Power for Solid-State Lighting and Methods Thereof," Office Action mailed May 9, 2016 for U.S. Appl. No. 14/806,500, 18 pages.
Reed, "High Efficiency Power Controller for Luminaire," Notice of Allowance mailed Apr. 11, 2016, for U.S. Appl. No. 14/546,354, 5 pages.
Reed, "Low Power Photocontrol for Luminaire," Office Action mailed Apr. 27, 2016, for U.S. Appl. No. 14/844,944, 10 pages.
Reed, "Solid State Hospitality Lamp," Office Action mailed Apr. 15, 2016, for U.S. Appl. No. 13/973,696, 11 pages.
Korean Office Action with English Translation, dated May 16, 2016, for corresponding KR Application No. 10-2011-7014088, 22 pages.
Reed et al., "Apparatus and Method for Schedule Based Operation of a Luminaire," Amendment filed Jun. 7, 2016, for U.S. Appl. No. 14/552,274, 14 pages.
Reed, "Low Power Photocontrol for Luminaire," Amendment filed Jun. 13, 2016, for U.S. Appl. No. 14/844,944, 10 pages.

* cited by examiner

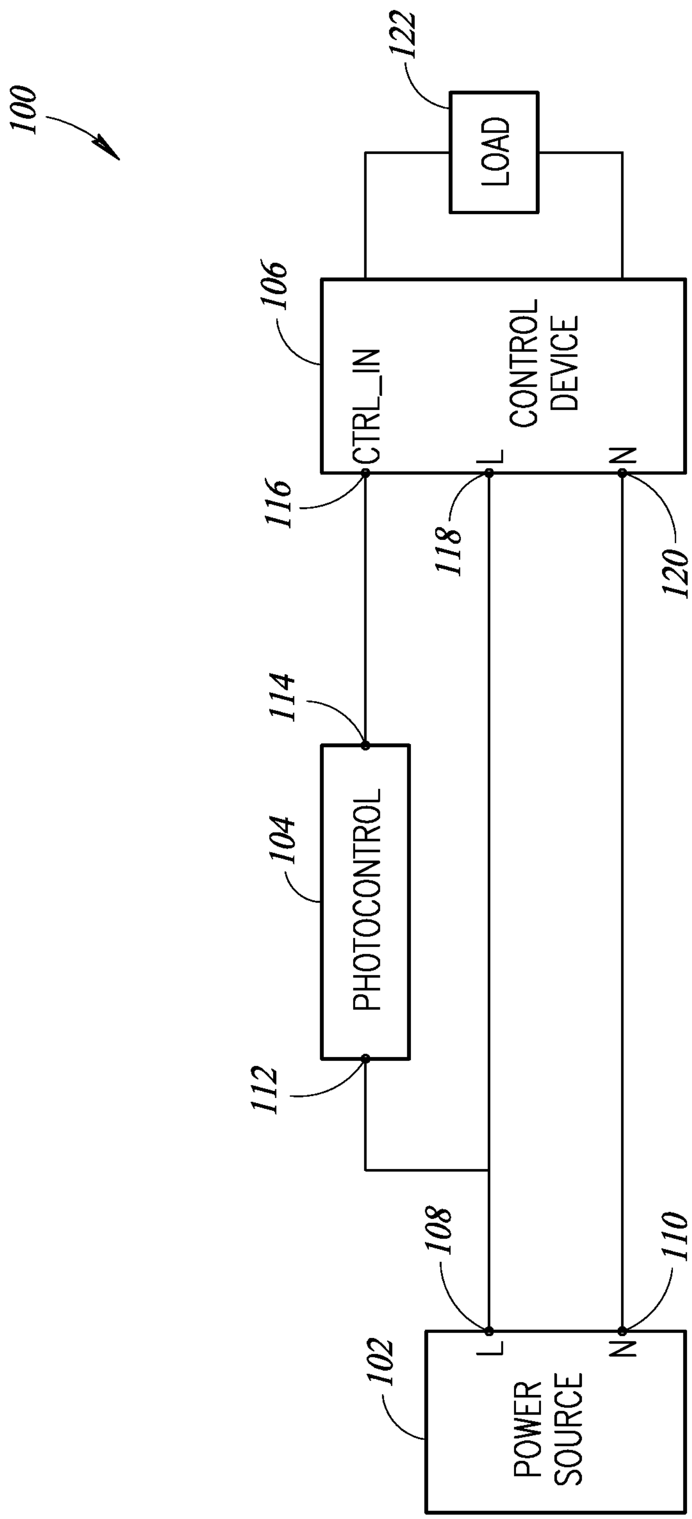

100
122
LOAD
106
CTRL_IN
CONTROL
DEVICE
L
N
116
118
120
114
104
PHOTOCONTROL
112
108
110
102
L
N
POWER
SOURCE

FIG.1

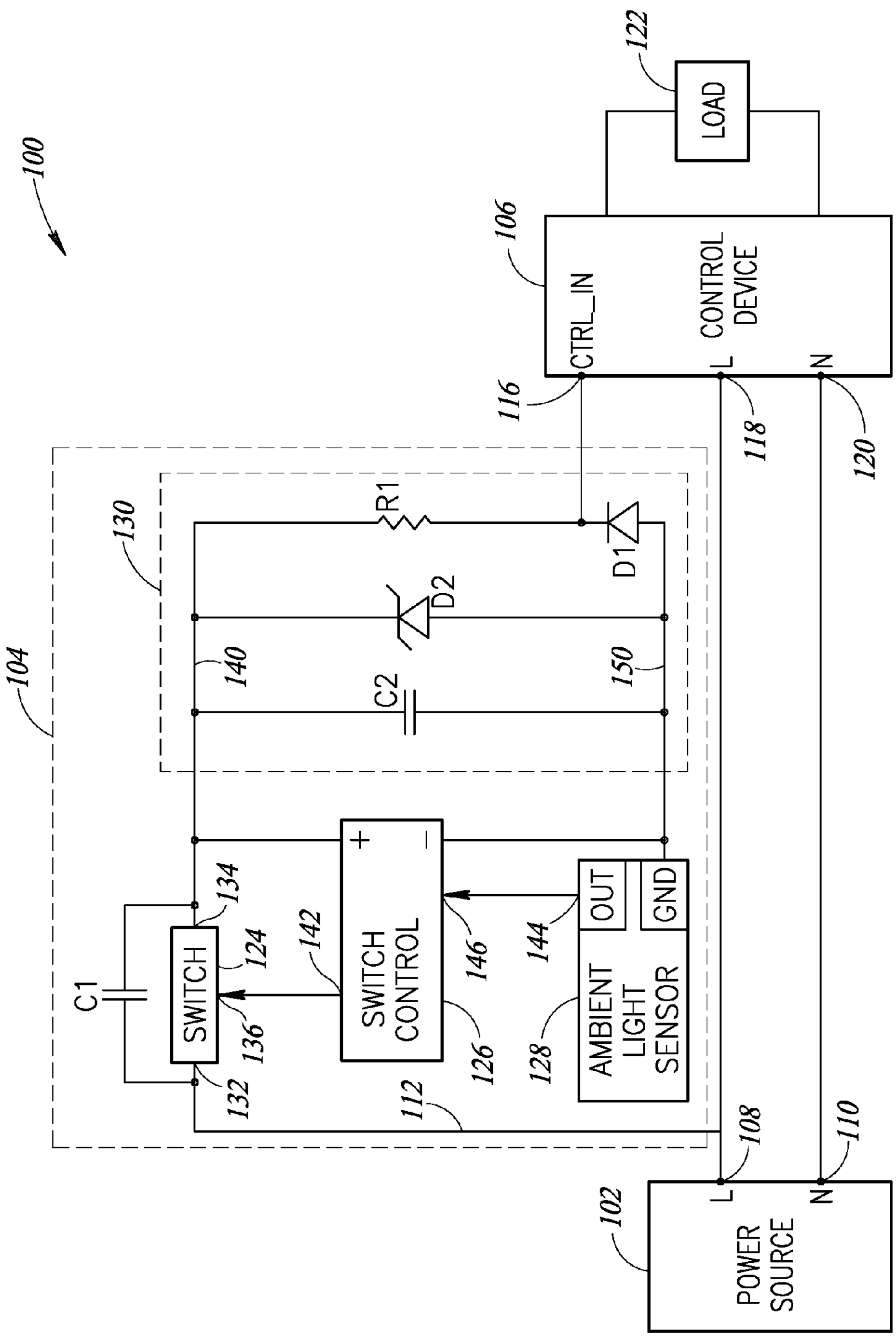

100
104
106
CTRL_IN
CONTROL DEVICE
L
N
LOAD
122
116
118
120
130
R1
D1
D2
C2
140
150
C1
SWITCH
SWITCH CONTROL
+
−
AMBIENT LIGHT SENSOR
OUT
GND
134
124
142
146
144
136
132
126
128
112
108
110
102
POWER SOURCE
L
N

FIG.2

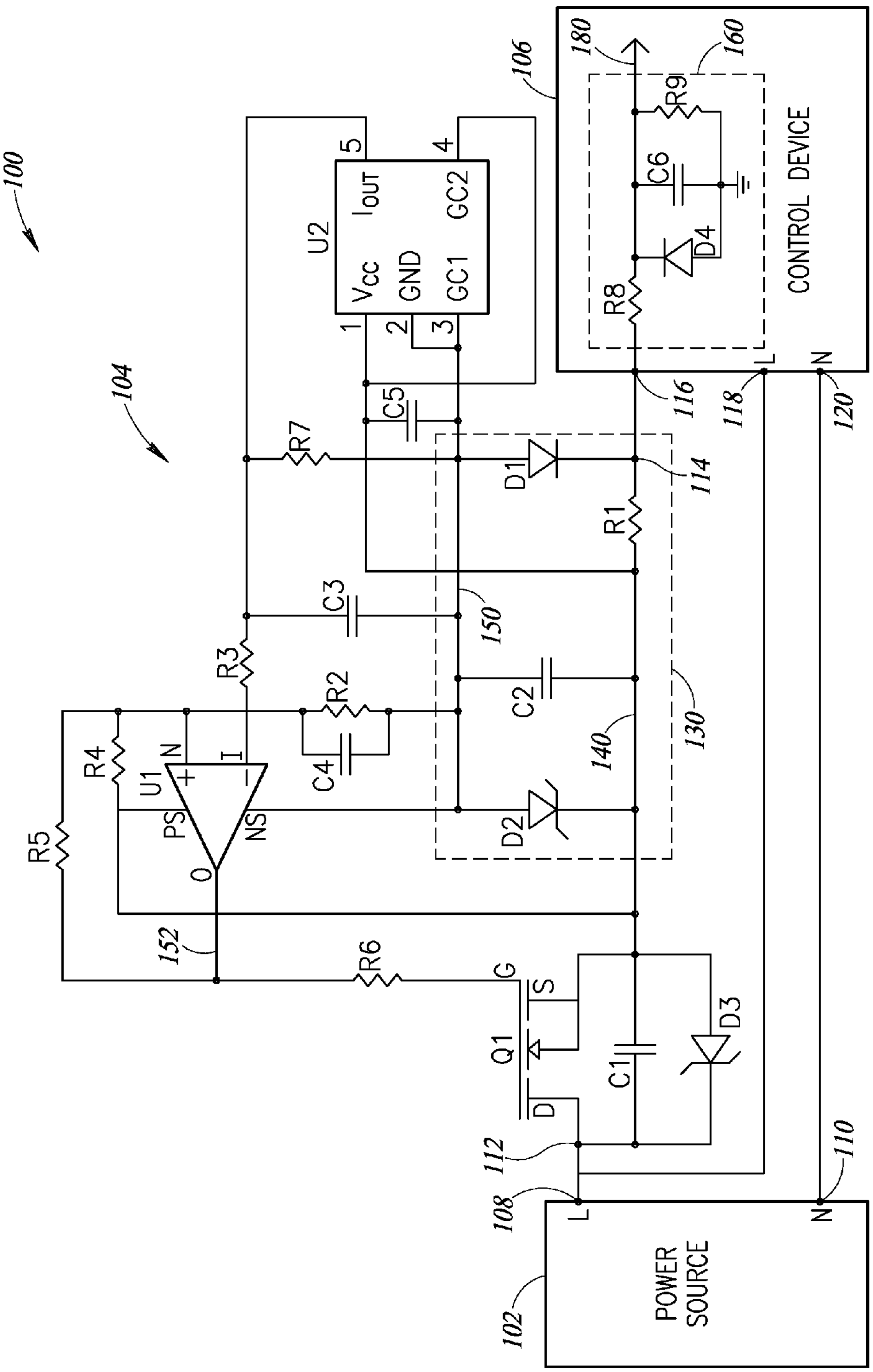

100
104
106
180
160
R9
C6
D4
R8
CONTROL DEVICE
U2
V_{CC}
GND
GC1
I_{OUT}
GC2
1
2
3
4
5
R7
C5
D1
R1
C3
C2
D2
R2
C4
R3
R4
R5
U1
N
I
PS
NS
O
+
−
R6
G
S
D
Q1
C1
D3
L
N
112
108
110
114
116
118
120
130
140
150
152
POWER SOURCE
102

FIG.3

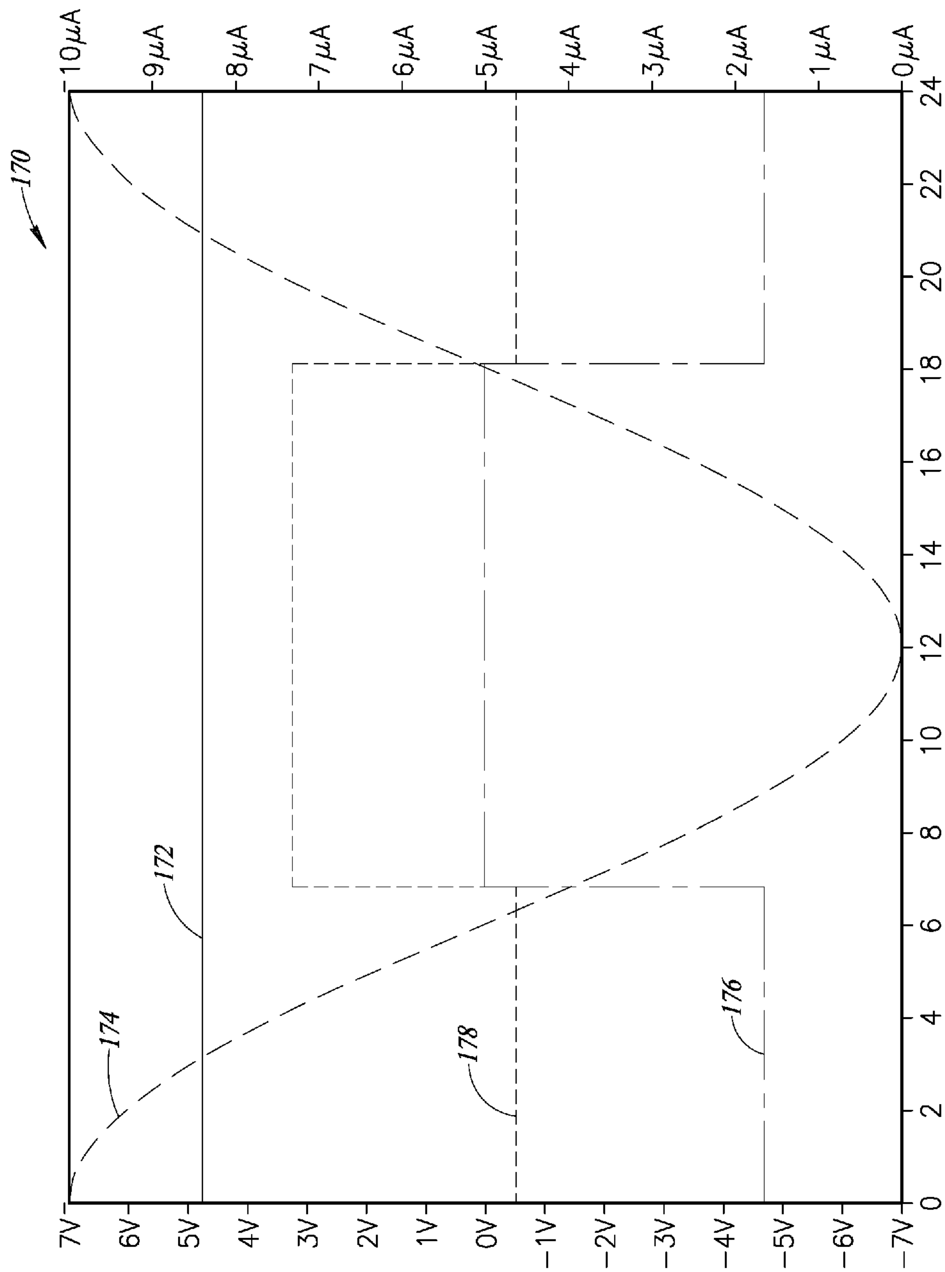

170
172
174
176
178
7V
6V
5V
4V
3V
2V
1V
0V
−1V
−2V
−3V
−4V
−5V
−6V
−7V
10μA
9μA
8μA
7μA
6μA
5μA
4μA
3μA
2μA
1μA
0μA
0
2
4
6
8
10
12
14
16
18
20
22
24

FIG.4

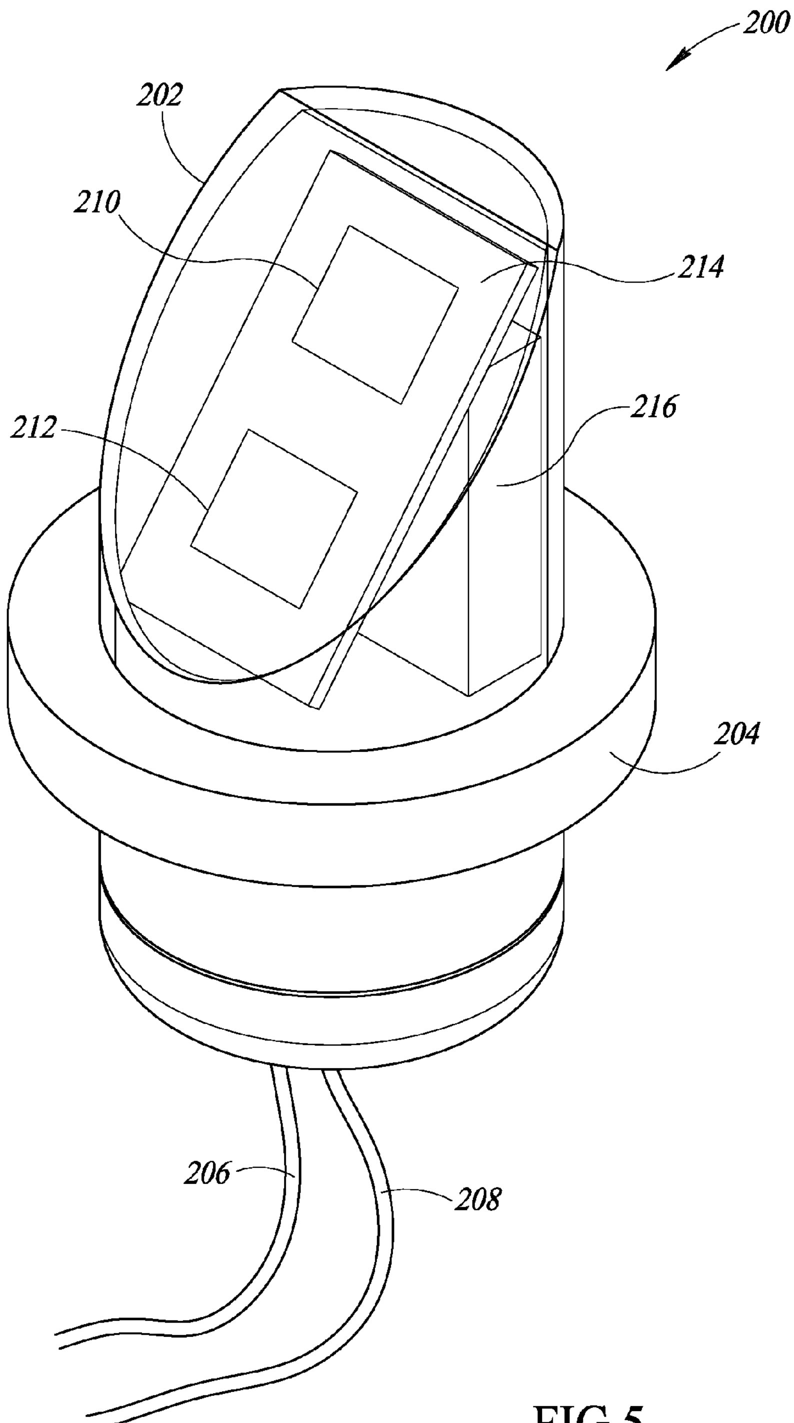


FIG.5

LOW POWER PHOTOCONTROL FOR LUMINAIRE

BACKGROUND

1. Technical Field

The present disclosure generally relates to the field of photocontrols and, more particularly, low-power photocontrols used with luminaires.

2. Description of the Related Art

A photocontrol is a device that switches or controls electrical loads based on ambient light levels. As an example, a photocontrol can be used as a switch that provides electrical power to a luminaire only when detected light levels are below a desired level. Photocontrols used for such luminaires may include photosensors that are electrically and operably coupled to switching devices rated for use at relatively high line voltages (e.g., 90 VAC to 600 VAC) and at relatively high currents (e.g., amperes and higher). For example, a photocontrol for a luminaire may include a photosensor that controls an electro-mechanical relay coupled between a source of electrical power and a control device (e.g., a magnetic or electronic transformer) within the luminaire. The electro-mechanical relay may be configured to be in an electrically continuous state unless a signal from the photosensor is present to supply power to the luminaire. If the photosensor is illuminated with a sufficient amount of light, the photosensor outputs the signal that causes the electro-mechanical relay to switch to an electrically discontinuous state such that no power is supplied to the luminaire.

Conventional photocontrols used with luminaires suffer from a number of drawbacks. For example, such photocontrols may include small power sources that use "capacitive drop" technology to power a circuit of discrete transistors, integrated circuit operational amplifiers, or comparators. Conventional photocontrols using such technology can consume considerable amounts of power when the luminaire is ON and when the luminaire is OFF.

Additionally, a typical electro-mechanical relay used with a photocontrol for a luminaire has a relatively short life span. For example, electro-mechanical relays of conventional photocontrols used with luminaries may be rated to have only 5000 contactor closures with standard loads. Arching caused by high capacitive in-rush currents of electronically ballasted luminaires and inductive "kick back" of magnetically ballasted luminaires can corrode the contactors of the electro-mechanical relays. Additionally, the contactors may include silver or other metal alloys upon which oxides and sulfides may form during normal operation. At line voltage and current, such oxides and sulfides may present a negligible resistance to the passage of current through the contactors. However, at relatively low voltages (e.g., 2 V to 24 V) and relatively low currents (e.g., μA) such as those used for digital logic level signaling, the impedance presented by contaminants including oxide and sulfide accumulations can hinder or even prevent the transmission of current through the contactors. Thus, conventional photocontrols for luminaires can be unsuitable for use in applications where the switching of relatively low voltage and relatively low current signals is required, for example, with luminaires that include solid-state light source drivers, for example, light emitting diode (LED) drivers that receive control signals for dimming LED arrays.

In response to the increasing emphasis placed on energy efficiency, many luminaires are being retrofitted with more energy efficient light sources. For example, conventional light sources (e.g., incandescent lights) are being replaced with solid-state light sources (e.g., LED arrays). Circuitry that regulates electrical power supplied to such solid-state light source (e.g., LED drivers) may draw relatively high inrush currents when the light sources are switched on. The inrush currents of electrically ballasted light sources may cause more damage to the contactors of electro-mechanical relays than is caused by the kickback currents of magnetically ballasted light sources. Accordingly, when conventional photocontrols having electro-mechanical relays are used with luminaires having solid-state light sources, the electro-mechanical relays may fail or cease to function reliably well before their rated number of contactor closures.

There is therefore a need for photocontrols that consume very small amounts of power. Additionally, there is a need for photocontrols that can be used reliably over long periods of time with luminaires having solid-state light sources.

BRIEF SUMMARY

A photocontrol apparatus to provide a control signal to a high-impedance controller input used to control a delivery of power to a load device may be summarized as including a resistor having a first node and a second node; a switch including a first node, a second node, and a third node, the first node electrically coupled to a line node of an alternating current (AC) power source and the third node electrically coupled to the first node of the resistor, wherein the second node of the resistor is an output node of the photocontrol that is electrically coupleable to the high-impedance controller input; a first capacitor having a first node and a second node, the first node of the first capacitor electrically coupled to the first node of the switch and the second node of the first capacitor electrically coupled to the third node of the switch; a direct current (DC) power supply circuit that includes: a positive DC power supply node electrically coupled to the first node of the resistor; a negative DC power supply node; a second capacitor having a first node and a second node, the first node of the second capacitor electrically coupled to the positive DC power supply node and the second node of the second capacitor electrically coupled to the negative DC power supply node; a zener diode having a cathode and an anode, the cathode of the zener diode electrically coupled to the positive DC power supply node and the anode of the zener diode electrically coupled to the negative DC power supply node; and a diode having a cathode and an anode, the cathode of the diode electrically coupled to the second node of the resistor and the anode of the diode electrically coupled to the negative DC power supply node; a comparator including a first power supply input node, a second power supply input node, a first input node, a second input node, and an output node, wherein the output node is communicably coupled to the second node of the switch and one of the first and the second power supply input nodes of the comparator is electrically coupled to the positive DC power supply node of the DC power supply circuit and the other of the first and the second power supply input nodes of the comparator is electrically coupled to the negative DC power supply node of the DC power supply circuit; and an ambient light sensor having an output node electrically coupled to one of the first input node or the second input node of the comparator, the ambient light sensor at least partially causes a voltage level of the one of the first input node or the second input node to which the ambient light sensor is electrically coupled to change in response to the ambient light sensor being at least partially illuminated with light. The switch may be a depletion mode Metal Oxide Semiconductor Field Effect Transistor (MOSFET), the first node of the switch may be a drain node of the MOSFET, the second node of the switch may be a gate node of the MOSFET, and the third node of the switch may be a source node of the MOSFET.

The photocontrol apparatus may further include a transient voltage suppression diode having a cathode and an anode, the cathode of the transient voltage suppression diode electrically coupled to the first node of the switch and the anode of the transient voltage suppression diode electrically coupled to the third node of the switch. The first capacitor may have a capacitance less than or equal to 0.1 microfarads. The ambient light sensor may include at least one of a solar cell, a semiconductor photo diode, a cadmium sulfide (CDS) cell, or a semiconductor ambient light sensor. The resistor may have a resistance of at least 200 kilohms. The ambient light sensor may include a ground reference node electrically coupled to the negative DC power supply node of the DC power supply circuit.

The photocontrol apparatus may further include a third capacitor having a first node and a second node, the first node of the third capacitor electrically coupled to the output node of the ambient light sensor and the second node of the third capacitor electrically coupled to the negative DC power supply node of the DC power supply circuit. The resistor, the switch, the first capacitor, the second capacitor, the diode, the zener diode, and the comparator may be surface mount devices. The first capacitor may be a non-electrolytic capacitor. When the switch is in a first state and the ambient light sensor causes the voltage level of the one of the first input node or the second input node to which the output node of the ambient light sensor may be electrically coupled to fall below a first threshold voltage level the comparator causes the switch to change to a second state, and when the switch is in the second state and the ambient light sensor causes the voltage level of the one of the first input node or the second input node to which the output node of the ambient light sensor may be electrically coupled to rise above a second threshold voltage level the comparator causes the switch to change to the first state. The third node of the switch may output a first control signal when the switch is in the first state, and the third node of the switch may output a second control signal when the switch is in the second state.

The photocontrol apparatus may further include a reference voltage source electrically coupled to the one of the first input node or the second input node to which the output node of the ambient light sensor is not electrically coupled. The reference voltage source at least one of a diode or a voltage divider that may include at least two resistors. The comparator may be a comparator integrated circuit or an operational amplifier integrated circuit, or a comparator circuit composed of discrete components including a negative voltage supply node, a positive voltage supply node, a non-inverting input node, an inverting input node, and a voltage output node, and wherein the negative voltage supply node may be the first power supply input node, the positive voltage supply node may be the second power supply input node, the non-inverting input node may be the first input node, the inverting input node may be the second input node, and the voltage output node may be the output node.

The photocontrol apparatus may further include a housing at least partially enclosing the switch and the ambient light sensor, the housing including a translucent portion formed from at least one of polycarbonate or silicone.

A photocontrol apparatus to provide a control signal to a high-impedance controller input used to control a delivery of power to a load device may be summarized as including a resistor having a first node and a second node; a switch including a first node, a second node, and a third node, the first node electrically coupled to a line node of an alternating current (AC) power source and the third node electrically coupled to the first node of the resistor, wherein the second node of the resistor is an output node of the photocontrol that is electrically coupleable to the high-impedance controller input; a first capacitor having a first node and a second node, the first node of the first capacitor electrically coupled to the first node of the switch and the second node of the first capacitor electrically coupled to the third node of the switch; a direct current (DC) power supply circuit that includes: a positive DC power supply node electrically coupled to the first node of the resistor; a negative DC power supply node; a second capacitor having a first node and a second node, the first node of the second capacitor electrically coupled to the positive DC power supply node and the second node of the second capacitor electrically coupled to the negative DC power supply node; a voltage regulator having a first node and a second node, the first node of the voltage regulator electrically coupled to the positive DC power supply node and the second node of the voltage regulator electrically coupled to the negative DC power supply node; and a rectifier having a cathode and an anode, the cathode of the rectifier electrically coupled to the second node of the resistor and the anode of the rectifier electrically coupled to the negative DC power supply node; and a switch control circuit including a first power supply input node, a second power supply input node, a first input node, a second input node, and an output node, wherein the output node is communicably coupled to the second node of the switch, one of the first and the second power supply input nodes of the switch control circuit is electrically coupled to the positive DC power supply node of the DC power supply circuit and the other of the first and the second power supply input nodes of the switch control circuit is electrically coupled to the negative DC power supply node of the DC power supply circuit, and one of the first input node or the second input node of the switch control circuit is coupled to an output node of an ambient light sensor to receive a signal therefrom indicative of an ambient light level. The switch may be a depletion mode Metal Oxide Semiconductor Field Effect Transistor (MOSFET), the first node of the switch may be a drain node of the MOSFET, the second node of the switch may be a gate node of the MOSFET, and the third node of the switch may be a source node of the MOSFET.

The photocontrol apparatus may further include a transient voltage suppression diode having a cathode and an anode, the cathode of the transient voltage suppression diode electrically coupled to the first node of the switch and the anode of the transient voltage suppression diode electrically coupled to the third node of the switch. The first capacitor may have a capacitance less than or equal to 0.1 microfarads. The resistor may have a resistance of at least 200 kilohms.

The photocontrol apparatus may further include a third capacitor having a first node and a second node, the first node of the third capacitor electrically coupled to the output node of the ambient light sensor and the second node of the third capacitor electrically coupled to the negative DC power supply node of the DC power supply circuit. The resistor, the switch, the first capacitor, the second capacitor, the rectifier, the voltage regulator, and the switch control circuit may be surface mount devices. The first capacitor may be a non-electrolytic capacitor.

The photocontrol apparatus may further include a reference voltage source electrically coupled to the one of the first input node or the second input node of the switch control circuit to which the output node of the ambient light sensor is not electrically coupled. The reference voltage source at least one of a diode or a voltage divider that may include at least two resistors. The switch control circuit may include an operational amplifier including a negative voltage supply node, a positive voltage supply node, a non-inverting input node, an inverting input node, and a voltage output node, and wherein the negative voltage supply node may be the first power supply input node, the positive voltage supply node may be the second power supply input node, the non-inverting input node may be the first input node, the inverting input node may be the second input node, and the voltage output node may be the output node.

The photocontrol apparatus may further include a housing that at least partially encloses the switch, the housing including a translucent portion formed from at least one of polycarbonate or silicone.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

In the drawings, identical reference numbers identify similar elements or acts. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various elements and angles are not necessarily drawn to scale, and some of these elements may be arbitrarily enlarged and positioned to improve drawing legibility. Further, the particular shapes of the elements as drawn, are not necessarily intended to convey any information regarding the actual shape of the particular elements, and may have been solely selected for ease of recognition in the drawings.

FIG. **1** is a block diagram of a control system for a luminaire that includes a photocontrol, according to one illustrated implementation.

FIG. **2** is a high-level schematic diagram of a photocontrol that can be used in the control system of FIG. **1**, according to one illustrated implementation.

FIG. **3** is a detailed schematic diagram of a photocontrol that can be used in the control system of FIG. **1**, according to one illustrated implementation.

FIG. **4** is a hypothetical plot showing an output control signal of the photocontrol of FIG. **3** as a function of time, according to one illustrated implementation.

FIG. **5** is a perspective view of an example photocontrol assembly, according to one illustrated implementation.

DETAILED DESCRIPTION

In the following description, certain specific details are set forth in order to provide a thorough understanding of various disclosed implementations. However, one skilled in the relevant art will recognize that implementations may be practiced without one or more of these specific details, or with other methods, components, materials, etc. In other instances, well-known structures associated with computer systems, server computers, and/or communications networks have not been shown or described in detail to avoid unnecessarily obscuring descriptions of the implementations. In other instances, well-known mathematical and statistical methods for performing statistical analyses and other well-known mathematical operation have not been described in detail to avoid unnecessarily obscuring descriptions of the implementations.

Unless the context requires otherwise, throughout the specification and claims that follow, the word "comprising" is synonymous with "including," and is inclusive or open-ended (i.e., does not exclude additional, unrecited elements or method acts).

Reference throughout this specification to "one implementation" or "an implementation" means that a particular feature, structure or characteristic described in connection with the implementation is included in at least one implementation. Thus, the appearances of the phrases "in one implementation" or "in an implementation" in various places throughout this specification are not necessarily all referring to the same implementation. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more implementations.

As used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the content clearly dictates otherwise. It should also be noted that the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

The headings and Abstract of the Disclosure provided herein are for convenience only and do not interpret the scope or meaning of the implementations.

Implementations of the present disclosure provide a photocontrol apparatus (or "photocontrol") that controls a luminaire or other load such that the luminaire is switched on during nighttime hours and off during the daytime. The photocontrols discussed herein generate a microampere (μA) power supply using the voltage generated across a high value resistor in series with an alternating current (AC) power line, instead of using a solar cell to power the photocontrol. Further, unlike traditional "capacitor drop" or resistive power sources used in existing photocontrols which consume a relatively large amount of power, the supply voltage for the photocontrols of the present disclosure is developed across a series resistor rather than using a capacitor or resistor to limit the current to a voltage regulator (e.g., zener diode), which substantially reduces the amount of power required by the photocontrol.

The implementations of the photocontrols discussed herein consume only microwatts (μW) of power in either the ON or the OFF states, unlike traditional relay- or triac-based photocontrols. Advantageously, the implementations of the present disclosure do not require a voltage generating photo sensor to generate power for the photocontrol. Thus, unlike applications which require such a voltage generating photo sensor to generate power, a solar cell, a semiconductor photo diode or photo diode string, a cadmium sulfide (CDS) cell or a semiconductor ambient light sensor may be used as the sensor element.

FIG. **1** shows a control system **100**, according to one illustrated implementation. The description of FIG. **1** provides an overview of the structure and operation of the control system **100**. A power source **102** (e.g., mains power) provides electrical power to a photocontrol apparatus **104** and a control device **106**, for example, using electrically conductive wires. More particularly, the power source **102** provides line voltage from a line node **108**, which is electrically coupled to an input node **112** of the photocontrol apparatus **104** and to at line input node **118** of the control device **106**. A node **110** of the power source **102** is electrically coupled to system neutral and to node **120** of the control device **106**. An output control node **114** of the photocontrol apparatus **104** is electrically coupled to a high impedance control input node **116** of the control device **106**. The photocontrol apparatus **104** provides control signals to the control device **106** via the nodes **114** and **116**. As will be explained below, the control device **106** uses the control signals provided by the photocontrol apparatus **104** to control the supply of electrical power to a load device **122**, such as an array of LEDs.

If the photocontrol apparatus **104** is not illuminated with ambient light (e.g., during nighttime), the photocontrol apparatus **104** outputs a first control signal to the control device **106**. When the first control signal is received by the control device **106**, the control device **106** causes electrical power to be supplied to the load device **122**. For example, the control device **106** causes electrical power to be supplied to an array of LEDs such that the array of LEDs produces an amount of light. If the photocontrol apparatus **104** is illuminated with a sufficient amount of ambient light (e.g., during daytime), the photocontrol apparatus **104** outputs a second control signal to the control device **106**. When the second control signal is received by the control device **106**, the control device **106** reduces the amount of electrical power supplied to the load device **122**. For example, the control device **106** reduces or stops the supply of electrical power to an array of LEDs such that the array of LEDs produces less light, or no light at all.

FIG. **2** is a high-level schematic diagram of the control system **100** of FIG. **1** which shows the photocontrol apparatus **104** in further detail. The photocontrol apparatus **104** includes a switch **124**, a capacitor C**1** in parallel with the switch, a switch control circuit **126**, an ambient light sensor **128**, and a DC voltage supply circuit **130** used to power the switch control circuit. In some implementations, the capacitor C**1** has a capacitance value of 0.01 and a working voltage of 600 V. In some implementations, the photocontrol apparatus **104** also includes input conditioning circuitry and/or output conditioning circuitry.

In some implementations, the switch **124** is a low threshold, n-channel, depletion mode (normally-on) Metal Oxide Semiconductor Field Effect Transistor (MOSFET), such as transistor model CPC3980ZTR from IXYS Integrated Circuits Division. In some implementations, the switch **124** is a low threshold, p-channel, enhancement mode (normally-off) MOSFET. In some implementations, the switch **124** is a low RDS (on), n-channel enhancement mode MOSFET.

The switch **124** includes an input node **132**, an output node **134**, and a control input node **136**. For example, in some implementations, the input node **132** may be a drain node of an n-channel depletion mode MOSFET, the output node **134** may be a source node of the MOSFET, and the control input node **136** may be a gate node of the MOSFET.

The input node **132** is electrically coupled to the node **112**, which can be electrically coupled to the line node **108** of the power source **102**. The output node **134** is coupled to a positive DC supply node **140**, and to the output node **114** through a high value resistor R**1**. In some implementations, the resistor R**1** has a value that is greater than or equal to 200 kΩ (e.g., 510 kΩ). As noted above, the output node **114** of the photocontrol apparatus **104** is coupled to the control input node **116** of the control device **106** to provide a control signal to the control device. The control node **136** of the switch **124** is coupled to a control output node **142** of the switch control circuit **126**.

The ambient light sensor **128** includes an output node **144** electrically coupled to an input node **146** of the switch control circuit **126** to provide a signal to the switch control circuit indicative of an ambient light level. The ambient light sensor **128** may be any suitable component that generates a signal (e.g., voltage, current) responsive to ambient light. For example, the ambient light sensor **128** may include a solar cell such as a Panasonic AM-5610CAR solar cell, a semiconductor photo diode or photo diode string, a cadmium sulfide (CDS) cell, a semiconductor ambient light sensor with a voltage or current output, or a digital ambient light sensor with a pulse width modulated (PWM) output if suitable filtering is added to the PWM output to convert the output to a light-dependent voltage or current output. In some implementations, the ambient light sensor **128** is an analog current output type ambient light sensor integrated circuit (IC), such as model BH1620FVC from ROHM Co. Ltd. The ambient light sensor **128** and/or the switch control circuit **126** may include appropriate interfacing circuitry (not shown in FIG. **2**) which allows the switch control circuit to communicably receive the signals from the ambient light sensor.

The switch control circuit **126** is powered by the DC voltage supply circuit **130**, which creates a DC voltage across the positive DC supply node **140** and a negative DC supply node **150**. The DC voltage supply circuit **130** includes the series resistor R**1** coupled between the positive DC supply node **140** and the output node **114**, a diode D**1** coupled between the output node and the negative DC supply node **150**, a capacitor C**2** coupled between the positive DC supply node and the negative DC supply node, and a zener diode D**2** coupled between the positive DC supply node and the negative DC supply node. In some implementations, the capacitor C**2** has a capacitance of 10 μF. The DC supply voltage across the positive DC supply node **140** and the negative DC supply node **150** is generated by current passing through the resistor R**1**, which is rectified by the diode D**1**. The zener diode D**2** limits the supply voltage to a desired DC supply voltage (e.g., 3.3 V, 4.7 V, 6.2V). The capacitor C**2** filters the DC ripple to provide a substantially stable DC supply voltage to the switch control circuit **126**.

When light causes the ambient light sensor **128** to produce a sufficient amount of current or voltage or change in resistance, the switch control circuit **126** turns the switch **124** OFF. While the switch **124** is turned OFF, only a relatively small current flows through the capacitor C**1** to supply the DC voltage supply circuit **130** and the control signal provided to the input node **116** of the control device **106** has a relatively low voltage level. When little or no light strikes the ambient light sensor **128**, the switch control circuit **126** causes the switch **124** to turn ON. While the switch **124** is turned ON, a relatively high current can flow through the switch and the control signal provided to the input node **116** of the control device **106** can have a relatively high voltage level. The control device **106** uses this change in voltage levels at the input node **116** to selectively provide power to the load **122**.

FIG. **3** is a detailed schematic diagram of the control system **100** of FIG. **1** which shows the various components of the photocontrol apparatus **104** according to one or more implementations. The photo control apparatus **104** includes a switch Q**1**, the capacitor C**1** in parallel with the switch, and an ambient light sensor circuit U**2**. A transient voltage suppression (TVS) diode D**3** limits input transients that may exceed the maximum voltage rating of the switch Q**1**. In some implementations, the TVS diode D**3** is a model SMAJ440A TVS diode offered by Littelfuse, Inc.

The photocontrol apparatus **104** also includes a switch control circuit formed by a comparator U**1**, capacitors C**3** and C**4**, and resistors R**2**, R**3**, R**4**, R**5**, R**6**, and R**7**. In some implementations, capacitors C**3** and C**4** have capacitance values of 10 μF and 0.1 μF, respectively. In some implementations, the resistors R**2**, R**4** and R**7** have a resistance value of 1 MΩ. In some implementations, the resistors R**3** and R6 have a resistance value of 1 kΩ In some implementations, the resistor R5 has a resistance value of 6.8 MΩ. As also shown in FIG. 2, the photocontrol apparatus 104 further includes the DC voltage supply 130 formed by the resistor R1, the diode D1, the zener diode D2, and the capacitor C2. The DC voltage supply 130 provides a relatively constant DC voltage between the positive DC supply node 140 and the negative DC supply node 150.

In the illustrated implementation, the switch Q1 is a low threshold, n-channel, depletion mode (normally-on) Metal Oxide Semiconductor Field Effect Transistor (MOSFET), such as transistor model CPC3980ZTR from IXYS Integrated Circuits Division. The switch Q1 includes a drain node D, a source node S, and a gate node G.

The drain node D of the switch Q1 is electrically coupled to the input node 112 of the photocontrol apparatus 104, which can be electrically coupled to the node 108 of the power source 102 of FIG. 1. The source node S of the switch Q1 is coupled to the positive DC voltage supply node 140, and to the output node 114 through the high value resistor R1. The output node 114 of the photocontrol apparatus 104 is coupled to the control input node 116 of the control device 106 to provide a control signal to the control device. The gate node G of the switch Q1 is coupled to a control output node 152 of the comparator U2 via the resistor R6.

In the illustrated implementation, the ambient light sensor U2 is an analog current output type ambient light sensor integrated circuit (IC), such as model BH1620FVC from ROHM Co. Ltd. The ambient light sensor U2 includes a V_{cc} node, a GND node, an Iout node, and two gain control input control nodes GC1 and GC2 which control the gain of the ambient light sensor. The Vcc node is coupled to the positive DC supply node 140 and the GND node is coupled to the negative DC supply node 150. A capacitor C5 is coupled across the V_{cc} node and the GND node to provide a stable DC voltage to the ambient light sensor U2. In some implementations, the capacitor C5 has a capacitance value of 0.1 μF. The GC1 node is coupled to the negative DC supply node 150 and the GC2 node is coupled to the positive DC supply node 140, which programs the ambient light sensor U2 to be in a medium gain mode. In operation, the ambient light sensor U2 outputs a current at the Iout node which is substantially proportional to ambient illuminance detected by the ambient light sensor.

The comparator U1 includes a positive supply voltage node PS, a negative supply voltage node NS, an inverting input node I, a non-inverting input node N, and an output node O (labeled “152”). The inverting input node I of the comparator U1 is coupled to the Tout node of the ambient light sensor U2 through the resistor R3. The capacitor C3 filters noise from the Tout node of the light sensor U2. In some implementations, the comparator U1 is a model TLV3701 comparator from Texas Instruments Inc. In the illustrated implementation, the comparator U1 operates as a trigger with hysteresis (“Schmitt trigger”).

The positive supply voltage node PS of the comparator U1 is coupled to the positive DC supply node 140, which is also connected to the source node S of the switch Q1. The output node O of the comparator U1 is electrically coupled to the gate node G of the switch Q1 through the resistor R6. The resistor R5 is electrically coupled between the output node O of the comparator U1 and the non-inverting input node N of the comparator U1. The resistor R2 is electrically coupled between the non-inverting input node N of the comparator U1 and the negative DC supply node 150. The resistor R4 is electrically coupled between the non-inverting input node N of the comparator U1 and the positive DC supply node 140. The resistor R2 is electrically coupled between the inverting input node I of the comparator U1 and the negative DC supply node.

The resistor R5 provides positive feedback to the comparator U1, and causes the photocontrol apparatus to have switching hysteresis. The resistors R2 and R4 form a voltage divider that controls a reference voltage level at the non-inverting input node N of the comparator U1. The capacitor C4 bypasses noise so the reference voltage provided by the voltage divider will be relatively stable. In some implementations, the resistors R2 and R4 are included in a trimming potentiometer. In some implementations, a reference voltage may be provided using a semiconductor voltage reference or other voltage reference.

The comparator U1 and the ambient light sensor U2 are powered by the DC voltage supply circuit 130, which creates a DC voltage across the positive DC supply node 140 and the negative DC supply node 150. The DC voltage supply circuit 130 includes the series resistor R1 coupled between the positive DC supply node 140 and the output node 114, the diode D1 coupled between the output node 114 and the negative DC supply node 150, the capacitor C2 coupled between the positive DC supply node and the negative DC supply node, and the zener diode D2 coupled between the positive DC supply node and the negative DC supply node. The DC supply voltage across the positive DC supply node 140 and the negative DC supply node 150 is generated by current passing through the resistor R1, which is rectified by the diode D1, the TVS diode D3, and a body diode (not shown) of the switch Q1. The zener diode D2 limits the supply voltage to a desired DC supply voltage (e.g., 3.3 V, 4.7 V, 6.25 V). In some implementations, the zener diode D2 may be a model BZX84C4V7LT1G zener diode manufactured by Semiconductor Components Industries, LLC (“ON Semiconductor”), which has a reverse zener voltage of approximately 4.7 V. The capacitor C2 filters the DC ripple to provide a substantially stable DC supply voltage to the comparator U1 and the ambient light sensor U2.

As shown in FIG. 3, the input of the control device 106 includes an input conditioner circuit 160 which includes a diode D4, a capacitor C6, and resistors R8 and R9. The input conditioner circuit 160 is coupled to the output node 114 of the photocontrol apparatus 104. In some implementations, the capacitor C6 has a value of 10 μF, the resistor R8 has a value of 1 MΩ, and the resistor R9 has a value of 100 kΩ. The values of the components of the input conditioner circuit 160 may be selected such that the control signals output by the photocontrol apparatus 104 have voltage and current levels that are compatible with the control device 106. For example, the values of the components of the input conditioner circuit 160 may be selected such that the control signals output by the photocontrol apparatus 104 are compatible with an enable control input or a dimming control input of an LED driver incorporated within the AreaMax™ LED Area Light provided by the Evluma division of Express Imaging Systems, LLC.

FIG. 4 is a hypothetical plot 170 which shows various signals of the photocontrol apparatus 104 shown in FIG. 3 as a function of time. Specifically, the plot 170 displays a trace 172 for the DC voltage supply voltage, which is the voltage between the positive DC supply node 140 and the negative DC supply node 150, through a 24 hour time period. In this illustration, the DC voltage supply voltage is set at approximately 4.7 V by the zener diode D2. The plot 170 also shows a trace 174 for the current output by the ambient light sensor U2 throughout the 24 hour period. Although shown in the plot 170 as a sinusoid for explanatory purposes, it should be appreciated that the shape of the current output by the ambient light sensor U2 may not be sinusoidal in practice. For example, the current output may be relatively constant for periods during the middle of the day and the middle of the night. Further, the slope of the current during transitions between day and night may be relatively steep in practice compared to the sinusoidal shape shown in FIG. **4**.

The plot **170** also shows a trace **176** of the voltage V_{GS} between the gate node and the source node S of the switch Q**1**. As discussed above, depletion mode MOSFETs are turned ON (i.e., low resistance) when V_{GS} is near zero volts, and are turned OFF (i.e., high resistance) when V_{GS} is more negative than a threshold voltage.

The plot **170** also shows a trace **178** of the voltage at an input conditioned node **180** (FIG. **3**) of the control device **106**, which is the signal provided as a control signal to the control device after the signal has been conditioned by the input conditioning circuit **160** of the control device.

When the switch Q**1** is ON and the ambient light sensor is producing little or no current (e.g., nighttime), the output of the comparator U**1** is the same as the voltage level of the source node S. As a result, V_{GS} is approximately 0 V and the switch Q**1** remains ON, which provides a relatively high voltage level signal at the output node **114** that is provided to the control device **106**. In the illustrated implementation, the voltage at the input conditioned node **180** is at about 3 V when the switch Q**1** is turned ON. If the ambient light sensor U**2** produces enough current to cause the voltage level at the inverting input node I of the comparator U**1** to rise above the voltage level at the non-inverting input node N of the comparator, the comparator outputs the voltage level provided to the negative power supply input node NS of the comparator. As result, V_{GS} drops to a negative value (e.g., −4.7 V) which is more negative than the threshold voltage of the switch Q**1** to cause the switch to turn OFF, which lowers the voltage of the signal at the output node **114** that is provided to the control device **106**. In the illustrated implementation, the voltage at the input conditioned node **180** is at about −0.4 V when the switch Q**1** is turned OFF. The control device **106** may utilize the changes in the control signal to control the operation of one or more light sources, such as an array of LEDs.

When the switch Q**1** is OFF and the ambient light sensor U**2** stops producing enough current to cause the voltage level at the inverting input node I of the comparator U**1** to be above the voltage level at the non-inverting input node N of the comparator, the comparator outputs the voltage level provided to the positive power supply input node PS of the comparator U**1**.

In the illustrated implementation, the switch Q**1** switches ON when the current of the ambient light sensor U**2** falls to approximately 4 μA. The switch Q**1** switches back OFF when the current of the ambient light sensor rises to approximately 5 μA. As noted above, the difference between the two switching points is due to the hysteresis resulting from the positive feedback provided by the resistor R**5** (FIG. **3**). Other levels of hysteresis may be provided by adjusting the values of resistors R**2**, R**4**, and/or R**5**. Hysteresis reduces the likelihood that optical or electrical noise will cause the photocontrol apparatus to switch at inappropriate times.

FIG. **5** is a perspective view of a photocontrol assembly **200**, according to one illustrated implementation. The photocontrol assembly **200** includes an upper transparent housing **202**, a lower portion **204**, and connecting wires **206** and **208** extending from the lower portion **204**. The photocontrol assembly **200** may be physically coupled to a luminaire (not shown) to provide photocontrol for the luminaire. A photocontrol apparatus circuit **210** and an ambient light sensor **212** may be mounted on a printed circuit board **214** that is attached to a mounting portion **216** of the lower portion **204** such that ambient light is able to pass through the transparent housing **202** and at least partially illuminate the ambient light sensor **212**. In this illustrated implementation, the ambient light sensor **212** is an integrated circuit but, as noted above, other types of ambient light sensors may be used.

In some implementations, an input node and an output node of the photocontrol apparatus circuit **210** are electrically coupled to the connecting wires **206** and **208**, respectively, of the photocontrol assembly **200**, respectively. In such implementations, the connecting wire **206** may be electrically coupled to the line node **108** of the power source **102** and the connecting wire **208** may be electrically coupled to the input node **116** of the control device **106**.

The ambient light sensor **212** and the photocontrol apparatus circuit **210** may be assembled in the same housing or in separate housings. At least a portion of the housing **202** may be made of substantially transparent or translucent molded plastic, such as polycarbonate or silicone, or there may be a window in an otherwise opaque housing which allows ambient light to illuminate the ambient light sensor.

One or more implementations of the present disclosure provide several advantages. For example, for a 120 VAC power source, implementations discussed herein may dissipate only 0.44 milliwatts, which is much less than the 500 milliwatts dissipated by a typical commercial photo control. As another example, for a 277 VAC power source, implementations discussed herein may dissipate 16 milliwatts, which is much less than the 2,500 milliwatts dissipated by a typical commercial photocontrol.

Additionally, the implementations of the present disclosure provide photocontrols with high reliability. The use of all solid-state low power circuitry for the photocontrol provides for a lifetime far longer than the light source which the photocontrol controls. In contrast, existing commercial photocontrols are rated at only 5000 cycles with an inductive load, and are rated for fewer cycles for a capacitive load (e.g., LED driver).

The implementations discussed herein are also compact in size. Previous photocontrols required a much larger power supply and a mechanical relay or large semiconductor switch. Additionally, implementations discussed herein may be realized using surface mount devices (SMD) only. Unlike previous photocontrols, the SMD components can be automatically placed and soldered during manufacturing, which increases reliability and lowers manufacturing cost. As another advantage, the photocontrols discussed herein do not require electrolytic capacitors. Previous photocontrols often utilized electrolytic capacitors instead of non-electrolytic capacitors (e.g., ceramic) for cost and space savings, thereby undesirably reducing reliability.

The foregoing detailed description has set forth various implementations of the devices and/or processes via the use of block diagrams, schematics, and examples. Insofar as such block diagrams, schematics, and examples contain one or more functions and/or operations, it will be understood by those skilled in the art that each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In one implementation, the present subject matter may be implemented via Application Specific Integrated Circuits (ASICs). However, those skilled in the art will recognize that the implementations disclosed herein, in whole or in part, can be equivalently implemented in standard integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more controllers (e.g., microcontrollers) as one or more programs running on one or more processors (e.g., microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of ordinary skill in the art in light of this disclosure.

Those of skill in the art will recognize that many of the methods or algorithms set out herein may employ additional acts, may omit some acts, and/or may execute acts in a different order than specified.

In addition, those skilled in the art will appreciate that the mechanisms taught herein are capable of being distributed as a program product in a variety of forms, and that an illustrative implementation applies equally regardless of the particular type of signal bearing media used to actually carry out the distribution. Examples of signal bearing media include, but are not limited to, the following: recordable type media such as floppy disks, hard disk drives, CD ROMs, digital tape, and computer memory.

The various implementations described above can be combined to provide further implementations. To the extent that they are not inconsistent with the specific teachings and definitions herein, all of the U.S. patents, U.S. patent application publications, U.S. patent applications, foreign patents, foreign patent applications and non-patent publications referred to in this specification, including U.S. Provisional Patent Application No. 61/052,924, filed May 13, 2008; U.S. Patent Publication No. US 2009/0284155, published Nov. 19, 2009; U.S. Provisional Patent Application No. 61/051,619, filed May 8, 2008; U.S. Pat. No. 8,118,456, issued Feb. 12, 2012; U.S. Provisional Patent Application No. 61/088,651, filed Aug. 13, 2008; U.S. Patent Publication No. US 2010/0090577, published Apr. 15, 2010; U.S. Provisional Patent Application No. 61/115,438, filed Nov. 17, 2008; U.S. Provisional Patent Application No. 61/154,619, filed Feb. 23, 2009; U.S. Patent Publication No. US2010/0123403, published May 20, 2010; U.S. Provisional Patent Application No. 61/174,913, filed May 1, 2009; U.S. Patent Publication No. US2010/0277082, published Nov. 4, 2010; U.S. Provisional Patent Application No. 61/180,017, filed May 20, 2009; U.S. Patent Publication No. US2010/0295946, published Nov. 25, 2010; U.S. Provisional Patent Application No. 61/229,435, filed Jul. 29, 2009; U.S. Patent Publication No. US2011/0026264, published Feb. 3, 2011; U.S. Provisional Patent Application No. 61/295,519, filed Jan. 15, 2010; U.S. Provisional Patent Application No. 61/406,490, filed Oct. 25 2010; U.S. Patent Publication No. US2011/0175518, published Jul. 21, 2011; U.S. Provisional Patent Application Ser. No. 61/333,983, filed May 12, 2010; U.S. Patent Publication No. US2010/0295454, published Nov. 25, 2010; U.S. Provisional Patent Application Ser. No. 61/346,263, filed May 19, 2010; U.S. Patent Publication No. US2010/0295455, published Nov. 25, 2010; U.S. Provisional Patent Application Ser. No. 61/357,421, filed Jun. 22, 2010; U.S. Patent Publication No. US2011/0310605, published Dec. 22, 2011; U.S. Patent Publication No. 2012/0262069, published Oct. 18, 2012; U.S. Non-Provisional patent application Ser. No. 13/212,074, filed Aug. 17, 2011; U.S. Provisional Patent Application Ser. No. 61/527,029, filed Aug. 24, 2011; U.S. Non-Provisional patent application Ser. No. 13/592,590, filed Aug. 23, 2012; U.S. Provisional Patent Application Ser. No. 61/534,722, filed Sep. 14, 2011; U.S. Non-Provisional patent application Ser. No. 13/619,085, filed Sep. 14, 2012; U.S. Provisional Patent Application Ser. No. 61/567,308, filed Dec. 6, 2011; U.S. Provisional Patent Application Ser. No. 61/561,616, filed Nov. 18, 2011; U.S. Provisional Patent Application Ser. No. 61/641,781, filed May 2, 2012; U.S. Non-Provisional patent application Ser. No. 13/411,321, filed Mar. 2, 2012; U.S. Provisional Patent Application Ser. No. 61/640,963, filed May 1, 2012; U.S. Provisional Patent Application No. 61/764,395, filed Feb. 13, 2013; U.S. Non-Provisional patent application Ser. No. 13/558,191, filed Jul. 25, 2012; U.S. Provisional Patent Application Ser. No. 61/692,619, filed Aug. 23, 2012; U.S. Provisional Patent Application Ser. No. 61/694,159, filed Aug. 28, 2012; U.S. Non-Provisional patent application Ser. No. 13/604,327, filed Sep. 5, 2012; U.S. Provisional Patent Application Ser. No. 61/723,675, filed Nov. 7, 2012; U.S. Non-Provisional patent application Ser. No. 13/679,687, filed Nov. 16, 2012; U.S. Provisional Patent Application Ser. No. 61/728,150, filed Nov. 19, 2012; U.S. Provisional Patent Application Ser. No. 61/764,395, filed Feb. 13, 2013; Provisional patent application Ser. No. 13/786,114, filed Mar. 5, 2013; U.S. Non-Provisional patent application Ser. No. 13/786,332, filed Mar. 5, 2013; U.S. Non-Provisional patent application Ser. No. 13/875,000, filed May 1, 2013; U.S. Provisional Patent Application No. 61/849,841, filed Jul. 24, 2013; U.S. Provisional patent application Ser. No. 13/973,696, filed Aug. 22, 2013; U.S. Provisional Patent Application No. 61/878,425, filed Sep. 16, 2013; U.S. Non-Provisional patent application Ser. No. 14/074,166, filed Nov. 7, 2013; U.S. Provisional Patent Application No. 61/905,699, filed Nov. 18, 2013; U.S. Provisional Patent Application No. 61/933,733, filed Jan. 30, 2014; U.S. Provisional Patent Application No. 62/057,419, filed Sep. 30, 2014, U.S. Provisional Patent Application No. 62/068,517, filed Oct. 24, 2014; U.S. Non-Provisional patent application Ser. No. 14/546,354 filed on Nov. 18, 2014; U.S. Provisional Patent Application No. 62/082,463, filed Nov. 20, 2014; U.S. Non-Provisional patent application Ser. No. 14/552,274 filed on Nov. 24, 2014; U.S. Non-Provisional patent application Ser. No. 14/557,275 filed on Dec. 1, 2014; PCT Application No. US2015/013512 filed on Jan. 29, 2015; U.S. Non-Provisional patent application Ser. No. 14/609,168 filed on Jan. 29, 2015 and U.S. Provisional Patent Application No. 62/137,666 filed on Mar. 24, 2015 are incorporated herein by reference, in their entirety. Aspects of the implementations can be modified, if necessary, to employ systems, circuits and concepts of the various patents, applications and publications to provide yet further implementations.

These and other changes can be made to the implementations in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the claims to the specific implementations disclosed in the specification and the claims, but should be construed to include all possible implementations along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

The invention claimed is:

1. A photocontrol apparatus to provide a control signal to a high-impedance controller input used to control a delivery of power to a load device, the photocontrol apparatus comprising:

a resistor having a first node and a second node;

a switch including a first node, a second node, and a third node, the first node electrically coupled to a line node of an alternating current (AC) power source and the third node electrically coupled to the first node of the resistor, wherein the second node of the resistor is an output node of the photocontrol that is electrically coupleable to the high-impedance controller input;

a first capacitor having a first node and a second node, the first node of the first capacitor electrically coupled to the first node of the switch and the second node of the first capacitor electrically coupled to the third node of the switch;

a direct current (DC) power supply circuit that includes:

a positive DC power supply node electrically coupled to the first node of the resistor;

a negative DC power supply node;

a second capacitor having a first node and a second node, the first node of the second capacitor electrically coupled to the positive DC power supply node and the second node of the second capacitor electrically coupled to the negative DC power supply node;

a zener diode having a cathode and an anode, the cathode of the zener diode electrically coupled to the positive DC power supply node and the anode of the zener diode electrically coupled to the negative DC power supply node; and

a diode having a cathode and an anode, the cathode of the diode electrically coupled to the second node of the resistor and the anode of the diode electrically coupled to the negative DC power supply node;

a comparator including a first power supply input node, a second power supply input node, a first input node, a second input node, and an output node, wherein the output node is communicably coupled to the second node of the switch and one of the first and the second power supply input nodes of the comparator is electrically coupled to the positive DC power supply node of the DC power supply circuit and the other of the first and the second power supply input nodes of the comparator is electrically coupled to the negative DC power supply node of the DC power supply circuit; and

an ambient light sensor having an output node electrically coupled to one of the first input node or the second input node of the comparator, the ambient light sensor at least partially causes a voltage level of the one of the first input node or the second input node to which the ambient light sensor is electrically coupled to change in response to the ambient light sensor being at least partially illuminated with light.

2. The photocontrol apparatus of claim **1** wherein the switch is a depletion mode Metal Oxide Semiconductor Field Effect Transistor (MOSFET), the first node of the switch is a drain node of the MOSFET, the second node of the switch is a gate node of the MOSFET, and the third node of the switch is a source node of the MOSFET.

3. The photocontrol apparatus of claim **1**, further comprising:

a transient voltage suppression diode having a cathode and an anode, the cathode of the transient voltage suppression diode electrically coupled to the first node of the switch and the anode of the transient voltage suppression diode electrically coupled to the third node of the switch.

4. The photocontrol apparatus of claim **1** wherein the first capacitor has a capacitance less than or equal to 0.1 microfarads.

5. The photocontrol apparatus of claim **1** wherein the ambient light sensor comprises at least one of a solar cell, a semiconductor photo diode, a cadmium sulfide (CDS) cell, or a semiconductor ambient light sensor.

6. The photocontrol apparatus of claim **1** wherein the resistor has a resistance of at least 200 kilohms.

7. The photocontrol apparatus of claim **1** wherein the ambient light sensor includes a ground reference node electrically coupled to the negative DC power supply node of the DC power supply circuit.

8. The photocontrol apparatus of claim **1**, further comprising:

a third capacitor having a first node and a second node, the first node of the third capacitor electrically coupled to the output node of the ambient light sensor and the second node of the third capacitor electrically coupled to the negative DC power supply node of the DC power supply circuit.

9. The photocontrol apparatus of claim **1** wherein the resistor, the switch, the first capacitor, the second capacitor, the diode, the zener diode, and the comparator are surface mount devices.

10. The photocontrol apparatus of claim **1** wherein the first capacitor is a non-electrolytic capacitor.

11. The photocontrol apparatus of claim **1** wherein when the switch is in a first state and the ambient light sensor causes the voltage level of the one of the first input node or the second input node to which the output node of the ambient light sensor is electrically coupled to fall below a first threshold voltage level the comparator causes the switch to change to a second state, and when the switch is in the second state and the ambient light sensor causes the voltage level of the one of the first input node or the second input node to which the output node of the ambient light sensor is electrically coupled to rise above a second threshold voltage level the comparator causes the switch to change to the first state.

12. The photocontrol apparatus of claim **11** wherein the third node of the switch outputs a first control signal when the switch is in the first state, and the third node of the switch outputs a second control signal when the switch is in the second state.

13. The photocontrol apparatus of claim **1**, further comprising:

a reference voltage source electrically coupled to the one of the first input node or the second input node to which the output node of the ambient light sensor is not electrically coupled.

14. The photocontrol apparatus of claim **13** wherein the reference voltage source at least one of a diode or a voltage divider that includes at least two resistors.

15. The photocontrol apparatus of claim **1** wherein the comparator is a comparator integrated circuit or an operational amplifier integrated circuit, or a comparator circuit composed of discrete components including a negative voltage supply node, a positive voltage supply node, a non-inverting input node, an inverting input node, and a voltage output node, and wherein the negative voltage supply node is the first power supply input node, the positive voltage supply node is the second power supply input node, the non-inverting input node is the first input node, the inverting input node is the second input node, and the voltage output node is the output node.

16. The photocontrol apparatus of claim **1**, further comprising:

a housing at least partially enclosing the switch and the ambient light sensor, the housing including a translucent portion formed from at least one of polycarbonate or silicone.

17. A photocontrol apparatus to provide a control signal to a high-impedance controller input used to control a delivery of power to a load device, the photocontrol apparatus comprising:

a resistor having a first node and a second node;

a switch including a first node, a second node, and a third node, the first node electrically coupled to a line node of an alternating current (AC) power source and the third node electrically coupled to the first node of the resistor, wherein the second node of the resistor is an output node of the photocontrol that is electrically coupleable to the high-impedance controller input;

a first capacitor having a first node and a second node, the first node of the first capacitor electrically coupled to the first node of the switch and the second node of the first capacitor electrically coupled to the third node of the switch;

a direct current (DC) power supply circuit that includes:

a positive DC power supply node electrically coupled to the first node of the resistor;

a negative DC power supply node;

a second capacitor having a first node and a second node, the first node of the second capacitor electrically coupled to the positive DC power supply node and the second node of the second capacitor electrically coupled to the negative DC power supply node;

a voltage regulator having a first node and a second node, the first node of the voltage regulator electrically coupled to the positive DC power supply node and the second node of the voltage regulator electrically coupled to the negative DC power supply node; and

a rectifier having a cathode and an anode, the cathode of the rectifier electrically coupled to the second node of the resistor and the anode of the rectifier electrically coupled to the negative DC power supply node; and

a switch control circuit including a first power supply input node, a second power supply input node, a first input node, a second input node, and an output node, wherein the output node is communicably coupled to the second node of the switch, one of the first and the second power supply input nodes of the switch control circuit is electrically coupled to the positive DC power supply node of the DC power supply circuit and the other of the first and the second power supply input nodes of the switch control circuit is electrically coupled to the negative DC power supply node of the DC power supply circuit, and one of the first input node or the second input node of the switch control circuit is coupled to an output node of an ambient light sensor to receive a signal therefrom indicative of an ambient light level.

18. The photocontrol apparatus of claim 17 wherein the switch is a depletion mode Metal Oxide Semiconductor Field Effect Transistor (MOSFET), the first node of the switch is a drain node of the MOSFET, the second node of the switch is a gate node of the MOSFET, and the third node of the switch is a source node of the MOSFET.

19. The photocontrol apparatus of claim 17, further comprising:

a transient voltage suppression diode having a cathode and an anode, the cathode of the transient voltage suppression diode electrically coupled to the first node of the switch and the anode of the transient voltage suppression diode electrically coupled to the third node of the switch.

20. The photocontrol apparatus of claim 17 wherein the first capacitor has a capacitance less than or equal to 0.1 microfarads.

21. The photocontrol apparatus of claim 17 wherein the resistor has a resistance of at least 200 kilohms.

22. The photocontrol apparatus of claim 17, further comprising:

a third capacitor having a first node and a second node, the first node of the third capacitor electrically coupled to the output node of the ambient light sensor and the second node of the third capacitor electrically coupled to the negative DC power supply node of the DC power supply circuit.

23. The photocontrol apparatus of claim 17 wherein the resistor, the switch, the first capacitor, the second capacitor, the rectifier, the voltage regulator, and the switch control circuit are surface mount devices.

24. The photocontrol apparatus of claim 17 wherein the first capacitor is a non-electrolytic capacitor.

25. The photocontrol apparatus of claim 17, further comprising:

a reference voltage source electrically coupled to the one of the first input node or the second input node of the switch control circuit to which the output node of the ambient light sensor is not electrically coupled.

26. The photocontrol apparatus of claim 25 wherein the reference voltage source at least one of a diode or a voltage divider that includes at least two resistors.

27. The photocontrol apparatus of claim 17 wherein the switch control circuit comprises an operational amplifier including a negative voltage supply node, a positive voltage supply node, a non-inverting input node, an inverting input node, and a voltage output node, and wherein the negative voltage supply node is the first power supply input node, the positive voltage supply node is the second power supply input node, the non-inverting input node is the first input node, the inverting input node is the second input node, and the voltage output node is the output node.

28. The photocontrol apparatus of claim 17, further comprising:

a housing that at least partially encloses the switch, the housing including a translucent portion formed from at least one of polycarbonate or silicone.

* * * * *